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Vol. 20, N.S., Nos. 1–7. JULY, 1931.

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4.—PHOTO-ELECTRIC MEASUREMENTS OF ILLUMINATION IN RELATION TO PLANT DISTRIBUTION. Part 4. CHANGES IN THE COLOUR COMPOSITION OF DAYLIGHT IN THE OPEN AND IN SHADED SITUATIONS. By W. R. G. Atkins, Sc.D., F.R.S., and H. H. Poole, Sc.D.

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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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By H. H. POOLE, Sc.D.

(Plate 1.)

[Read November 25. Published separately December 9, 1930.]

When the radon capillary method of using radium for therapeutic purposes was developed by Professor Joly and Dr. W. Stevenson in 1914, an apparatus was set up in the Society's laboratory by Mr. R. J. Moss for drawing off the radon at intervals and introducing it into capillary glass tubes. This remained in use in its original form for some 14 years, during which time over 100,000 millicuries of radon were dealt with. The apparatus was simple, the process of purification being carried out in separate stages in independent parts of it, and could be trusted to give a yield of 90 per cent. in the hands of a skilled operator. It, however, required very skilful manipulation, and entailed considerable exposure of the operator's fingers to the radiations.

With growing demands for radon, and increasing supplies of radium, it became necessary to take every possible step to safeguard the operator from risk of injury. This entailed the development of an apparatus which should be as far as possible self-acting, the manipulations required being as few and as simple as possible, so that the work could safely be entrusted to students of the Universities, thus enabling a continuous succession of operators to be employed. It is found that with the apparatus described below an operator may carry out the work for at least a year without showing the smallest trace of injury.

As before, the usual sequence of operations is employed. The flasks containing the radium solutions are evacuated by means of a mercury pump, and the mixed gas drawn off is transferred to a eudiometer, where the hydrogen and oxygen are recombined. The residue, containing the excess of hydrogen along with any other gases, such as nitrogen, that may be present, is then allowed to stand for a short time over potash to remove carbon-dioxide, after which it is drawn into a tube surrounded by liquid air, which causes the radon to freeze. This tube is then exhausted to such a degree that, on the removal of the liquid

air, the small volume of gas left containing almost all the original radon may be drawn into a capillary tube. The apparatus is set up in a small fire-proof room at some distance from the parts of the laboratory that are usually occupied. A photograph taken by artificial light through the door of this room is shown in Pl. 1. The radium chloride or radium bromide solutions are stored in three round-bottomed flasks, each of about 60 c.c. capacity, which are mounted behind the heavy lead screen A. The necks of these flasks are about 12 mm. bore, and are connected by tapered ground joints to vertical tubes of the same size. These are sealed in a horizontal connecting tube, and continue above it, terminating in stop-cocks and open tubes of the type shown in fig. 1. The tops of

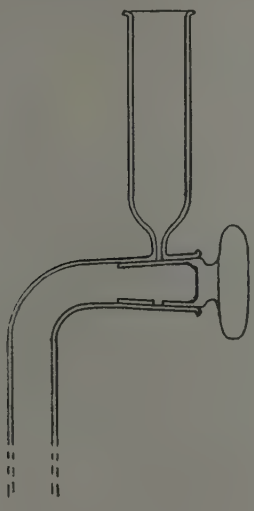


Fig. 1. Scale 1/2.

Fig. 2. Scale 1/1.

two of these tubes can be seen in the photograph above the top of the screen. Each of them can hold about 10 c.c. of liquid, which may be allowed to run down into the radium flask below without admission of air by careful manipulation of the stop-cock. This admission of dilute acid is, of course, necessary every few months to make good losses due to evaporation and decomposition.

This type of stop-cock for the admission of liquid seems to be preferable to the ordinary straight-through or diagonal type; as, if a plug of hard grease forms in the aperture owing to the action of the radiations, there is much less danger of it being carried down into the radium solution, and its removal is a much simpler operation.

The horizontal tube connecting the flask leads to the vertical tube seen rising behind the screen, and thence, *via* a mercury trap hidden by the screen,

to the stop-cock B, and the vertical tube C, which is about 2 mm. bore. The lower end of this dips below the surface of a mercury basin standing on the table D, and the upper end is connected to the potash bulb seen near the top of the photo, and thence to the Sprengel mercury pump E. A barometer tube, seen just to the left of C, stands in the same mercury basin, so that the pressure in the apparatus can be read from outside the room by the kathetometer, part of which is seen at F.

The mixed gas is collected over mercury in the cylinder G (capacity about 100 c.c.), from which, by the manipulation of the two-way stop-cock H and the mercury reservoir I, it is transferred to the eudiometer J, and thence, after sparking, to the smaller cylinder (capacity about 35 c.c.), seen just to the left of G.

This operation must usually be performed in several stages, a few c.c. of gas being exploded and transferred to the smaller cylinder at each, so as to limit the violence of the explosions. When it is complete a few bubbles of air are passed up into G and transferred to J. I is then lowered, so that the air in J expands to a volume greater than that occupied by the gas during the explosions. This air is then transferred to the smaller cylinder. This operation is then repeated, so as to ensure that very little radon is left behind in the eudiometer and tubes.

The walls of the smaller gas cylinder are coated inside with solid KOH, the cylinder being readily detachable for this purpose. This in a few minutes absorbs any CO_2 that may be present in the residual gas, after which the gas is transferred to the vertical tube K, which is about 9 mm. bore and passes up through an enamelled iron funnel about 7 cm. deep containing liquid air. This funnel is enclosed in the cardboard cylinder L, the intervening space being lagged with wool, and containing a small electric heating element for warming up the apparatus after the removal of the liquid air.

A few centimetres above the top of L is the mercury-sealed rubber joint, illustrated in fig. 2, connecting K to the capillary tube, into which the radon is to be introduced. Part of this capillary, which is usually over 50 cm. long, is visible in the photo. The lower end of K is connected by pressure tubing to a mercury reservoir, supported by the cord seen passing over the pulleys behind the capillary. Initially this reservoir is lowered almost to the floor, and K is exhausted by the Hyvac oil-pump N into the open air through the tube O. The tube M is also connected to a mercury reservoir, so that the mercury level in it may be lowered, opening the way to the pump. When the exhaustion is complete this reservoir is raised until the small-bore tube connecting M and K is completely filled with mercury, the stop-cock in this tube being then closed.

When the gas containing the radon has been drawn into K by opening the stop-cock seen to the right of it, a few bubbles of air are introduced into the potash cylinder and drawn into K to "rinse" out the tubes. The mercury level in K is then raised to within a few centimetres of the bottom of L, and kept at this level for about 5 minutes to allow convection currents and diffusion time to bring almost all the radon in the tube into contact with the cold surface. The

mercury is then lowered, and raised again a few times to assist this process, and finally lowered, so that the tube can be exhausted by the pump. It is important to remember to lower the mercury in M before opening the stop-cock, as otherwise mercury may be drawn over into the drying tube, or even into the pump itself. The drying tube contains $CaCl_2$ and soda-lime, the latter being introduced to prevent any danger of CO_2, formed by the action of traces of radon on the oil in the pump, from diffusing back into K. A vacuum tube, which is just visible below the switch P, enables the operator to know when the exhaustion has been carried far enough. This switch allows either the vacuum tube or the eudiometer terminals to be connected to the small induction coil used to provide the discharge.

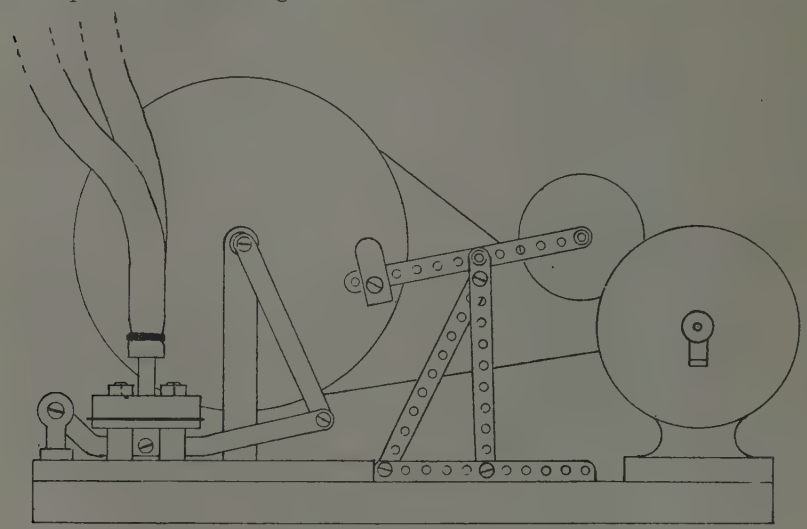


Fig. 3. Scale 1/4.

When the discharge through the tube assumes the deep red colour characteristic of hydrogen, and probably attributable chiefly to water vapour, the mercury in M is raised as before, and the stop-cock closed, the mercury in K is also raised again almost up to the bottom of L. The cork sheet covering the liquid air funnel is then removed, and the liquid air siphoned off. Gentle heat is applied by the electric heater until the hoar-frost disappears from the part of the tube inside the funnel. By raising the reservoir attached to K the gas remaining in the tube, including the re-evaporated radon, may then be transferred to the capillary. It is well in doing this to lower the mercury level again after it has been raised above L for the first time. This prevents the possibility of trapping frozen or occluded radon on cold parts of the tube, as these are warmed up by contact with the mercury, and when this is subsequently lowered the radon is set free.

The capillary, which has previously been marked off into lengths of 13 mm.

each by ink marks, is then sealed off by means of the gas-jet Q, and subdivided at the marked points by means of a slightly modified form of the apparatus described some years ago (Sci. Proc. R.D.S., **17**, 43, p. 37, 1924).

The yield of radon with this apparatus is generally very close to 90 per cent. Sometimes this figure is slightly exceeded. The Sprengel pump has the disadvantage that it is very much slower in action than the Toepler pump used in the old apparatus, taking about an hour and a half to effect a thorough exhaustion. This, however, is not a very serious drawback, as the pump is self-acting, the mercury being raised by a small motor-driven diaphragm pump,

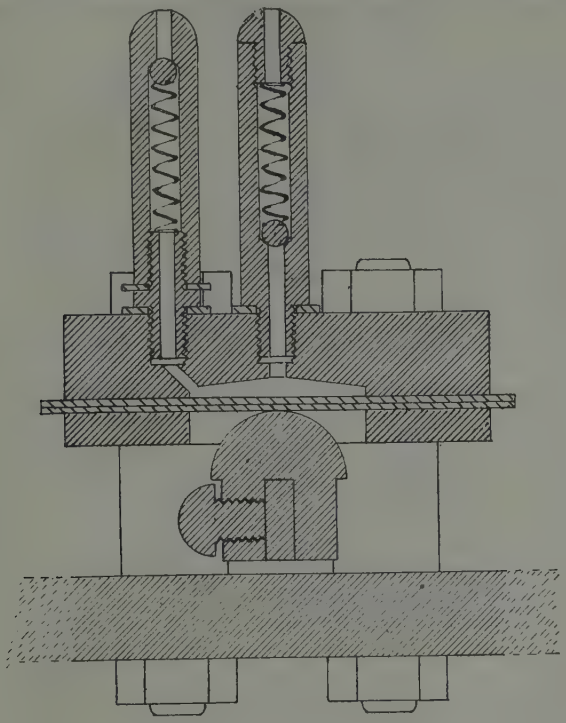


Fig. 4. Scale 1/1.

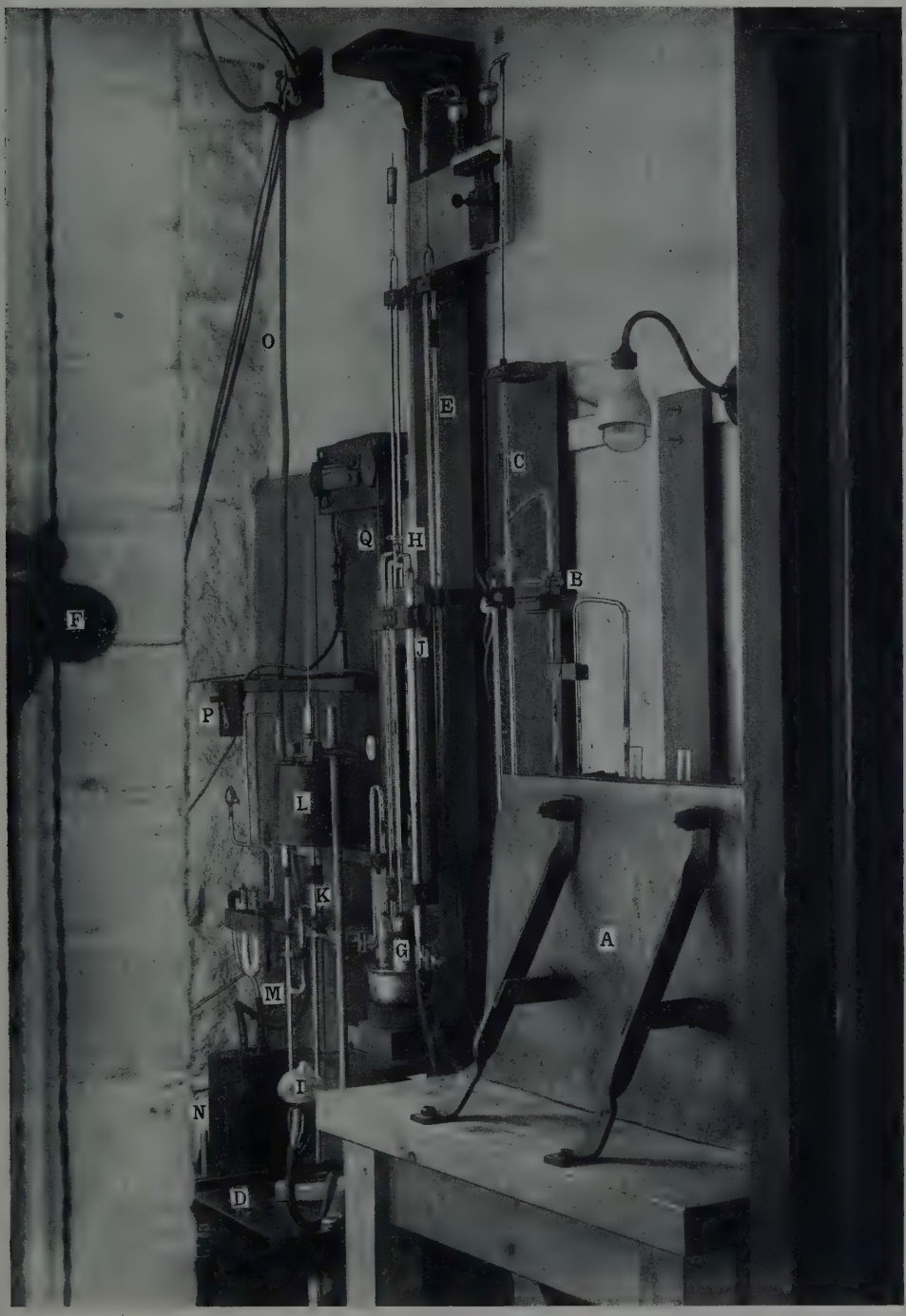
whose speed can be controlled from outside the radium room. Thus, the operator, having opened the tap C, need not again enter the radium room until the pumping is finished, unless it is necessary to fit a new capillary and re-exhaust the tube K, an operation which takes but little time, as the joint illustrated in fig. 2 is very quickly made, the rubber sleeve being bound with fine iron wire, and the internal and external mercury seals replaced by temporarily raising the mercury level in K and raising the outer mercury tube, which, of course, slides up and down so as to uncover the joint when necessary

Figures 3 and 4 show the pump used for raising the mercury. Fig. 3 is an

elevation showing the pump, with its pressure tube connections and the lever arrangement, designed to give the plunger a lift of about 1·7 mm., power being obtained from the small variable-speed motor indicated on the right, which is fitted with a small driving-pulley, so as to drive the large pulley, whose shaft carries the eccentric operating the pump, at 50 to 80 r.p.m. The "floating" jockey-pulley maintains a suitable tension on the thin flexible cord which is used as a belt. Fig. 4 shows a section of the pump itself, on a larger scale, in a plane normal to that of fig. 3. The pump is made entirely of iron or steel, with the exception of the double diaphragm, the lower layer of which is of chamois leather and the upper of thin sheet rubber, and of the rubber gaskets used to make the joints. The valves are formed by 3/16-inch bearing balls.

The pump is carried on a lower shelf of the table D. It is, thus, at some 60 cm. below the level of the mercury reservoir. This rather high pressure on the inlet side of the pump appears to be advantageous, as it ensures that the inlet valve always opens, which with a lower pressure it sometimes failed to do. On the other hand, the pressure on the outlet side is correspondingly raised, and amounts to about 180 cm. of mercury at the commencement of an exhaustion from air pressure, although in ordinary use it does not rise much above 120 cm. These pressures necessitate very carefully made wire bindings where the rubber tubes fit over the inlet and the outlet of the pump, and the lower part of the delivery tube must be prevented from bursting by means of a lapping of insulating tape.

The speed of the motor is adjusted by means of suitable lamp resistances outside the radium room, so that the falling mercury in the Sprengel pump breaks satisfactorily into drops. Apart from the small amount of attention that this requires the pump is quite automatic.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No. 2.

THE EXUDATION OF WATER FROM THE LEAF-TIPS OF *COLOCASIA ANTIQUORUM*, SCHOTT.

By HENRY H. DIXON, Sc.D., F.R.S.,
University Professor of Botany, Trinity College, Dublin,
AND
G. JOLY DIXON.

[Read November 25. Published separately December 11, 1930.]

In 1910 Dr. W. R. G. Atkins and one of us (1 and 2) found that the water exuded from the leaf-tips of *Colocasia antiquorum* has a freezing point not sensibly different from that of distilled water, and that its conductivity is less than that of tap-water. These observations were, at the time, taken to indicate that the liquid, osmotically inactive owing to its purity, must be secreted in this form by cellular activity.

Later, Flood (3) by histological examination showed that no such secreting cells exist at the point of exit of the water, and demonstrated experimentally that there is open communication between the channels of the wood and the perforations in the floor of the cavity of the leaf-tip from which the water issues.

By careful resection of the tissues it is possible to trace the exudation downwards to the root-stock and roots of the plant; but it is impossible to test the normal constitution of the liquid at these levels owing to the contamination introduced by the wounding of the tissues.

The question remains: Can we explain the rise of this pure water by simple osmosis, or are we to assign its production and elevation to secretion in the lower regions of the plant?

The mechanism of the rise of liquid in an osmometer is usually described somewhat as follows:—When a sugar solution containing 342 g. (one gram-molecule) of sucrose per 22·4 litres of water is placed in an osmometer and the membrane of the osmometer is immersed in pure water at 0° C., the water will pass into the osmometer, and the solution will rise in its tube, if the hydrostatic pressure exerted on the membrane is less than would be exerted by a column of 760 mm. of mercury; similarly, it will fall if the hydrostatic head is more than 760 mm. of mercury; and it will remain stationary when the pressure of the column of solution on the membrane is equal to that of a column of mercury 760 mm. high. In this the solute behaves like a gas which develops a pressure of one atmosphere when it occupies a volume of 22·4 litres. For this and for other

reasons it is natural to suppose that the osmotic pressure which raises the liquid column in the osmometer may be explained by a "bombardment" or kinetic theory similar to that which was found applicable to gaseous pressure. Thus the force which tends to extend the confines of the liquid in the osmometer may be regarded as due to the bombardment of the liquid surfaces from the inside by particles of the solute. The surfaces in contact with the membrane and walls of the osmometer are fixed in position, and hence expansion is only possible by the upward movement of the meniscus in the tube.

In Colocasia, since the water issuing from the pores is devoid of solutes, bombardment of the water-surface cannot be responsible for the elevation of the liquid.

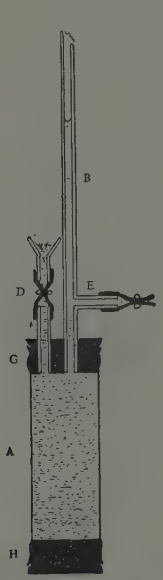

FIG. 1.

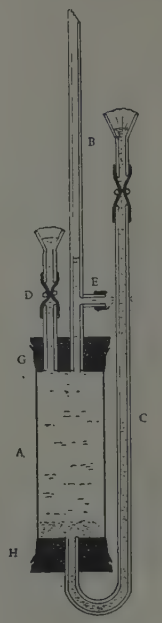

FIG. 2.

The state of affairs may be imitated experimentally.

A cylindrical dialysing parchment (fig. 1, A) was closed at each end by a rubber bung (G, H). The upper bung (G) was provided with two perforations—one, by which a solution might be introduced, and a second, into which a vertical tube (B) about one metre long was fixed. Just above the bung this tube was fitted with a side tubulure (E), which could be closed with a clip. Arrangements were also made for closing the filling tube. After the osmometer was filled with a solution this tube was closed with the clip (D), and distilled water was passed down the vertical tube (B) and allowed to flow out through the side tubulure (E). When it was certain that the whole vertical tube (B) and the side tubulure (E) were free from solutes, E was clipped, and at the same

time the level of the meniscus in B was adjusted about 30 cm. above E. A bath of pure water was then raised round the membrane of the osmometer.

Immediately after the immersion of the membrane the water in the vertical tube began to rise, and continued to rise for several hours at the rate of about 0·5 cm. per min., when 20 per cent. solutions of sucrose were used in the osmometer.

Here, of course, there can have been no question of internal bombardment of the upper surface, which was 30 cm. removed from the upper limits of the solution.

The rate of rise was sensibly the same when the same apparatus was arranged with the same solution not overlain with pure water.

Similar results were obtained with a 10 per cent. ferric chloride solution.

Further, it was found unnecessary to fill the whole osmometer membrane with the solution in order to obtain the lifting of the column in the tube. Thus by means of an U-tube (C, fig. 2) entering the osmometer through the lower bung a solution was introduced, displacing upwards distilled water, which had previously filled the apparatus. When the solution was about 5 cms. deep in the bottom of the osmometer, the side tubulure (E) and the U-tube (H) were closed, and the osmometer immersed in water. Even with this arrangement rapid rises, 0·3 to 0·5 cm. per min., were obtained with 35 per cent., 50 per cent., and 66 per cent. solutions of ferric chloride.

Thus, it is evident that the osmotic action of solutions in the lower parts of a plant is quite competent to cause the ejection of pure water from pores in the leaves.

The pure water itself may be derived from the solutions below by the abstraction of solutes by cells abutting on the channels of transport, or the pure water may be introduced by special processes into these channels above the osmotic solutions.

Experiments with Osmometers.

In the experiments carried out with the arrangements shown in fig. 1 the actual gains in volume of the contents of the osmometer per 30 min. per square centimetre of membrane are given below, together with corresponding gains for control experiments, in which both the tube and the membrane contained solution.

Table 1.

No. of Experiment.	Gain per 30 min. per sq. cm. of membrane.
1.	0·0086 c.c.
2.	0·0067 „
Control	0·0084 „
3.	0·0082 „
Control	0·0092 „
4.	0·0089 „

In Table 2 are given the results, obtained with the arrangement shown in fig. 2. In column (1) are entered the concentrations of the solutions used, in (2) the gains in c.c. of the contents of the osmometer per 30 min. per cm. of the membrane in contact with the solution, and in (3) are shown the proportions of the area of the membrane in contact with the solution ($A_{sol.}$) to the area of the membrane above the solution (A_w).

TABLE 2.

	Solution.	Gain.	$A_{sol.}/A_w$.
1.	Ferric chloride 67%	0·032	100/588
2.	„ „ 22%	0·035	100/621

In experiment (1) the estimation of the depth of the solution was only approximate.

Figs. 1 and 2.—A, osmometer membrane; B, osmometer tube; C, filling tube and funnel; D, clip on filling tube; E, side-tubulure on osmometer tube; F, bung closing upper end of osmometer membrane; G, bung closing lower end of osmometer; H, U-tube for displacing some of the water in the osmometer by solution.

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3. FLOOD, MARGARET G.—Exudation of water by *Colocasia antiquorum*. Sci. Proc. R. Dub. Soc., **15** (N.S.), No. 36, 1919; and Notes from the Botanical School of Trinity College, Dublin, **3**, p. 59.

No. 3.

THE APPLICATION OF GAMMA RADIATION TO DEEP-SEATED TUMOURS.—II.

By J. JOLY, Sc.D., F.R.S., F.T.C.D.,
Scientific Adviser to Dr. Steevens' Hospital.

[Read November 25. Published separately December 9, 1930.]

In April, this present year, I communicated to this Society a suggested method of applying gamma radiation to deep-seated tumours (Scient. Proc. R.D.S., **19**, No. 37, p. 447, 1930).

The suggested method involved the use of two radiators, pointing towards a common centre, which centre was supposed to be located in the tumour. The radiators are kept in a state of rotation around a common axis, and are, of course, adjustable as regards this axis so as to suit the case of a tumour located at any depth.

This system of two radiators is given a further motion, which carries them round a template shaped to the form of the tumour. Thus the focal area formed by the two converging rays is carried round the tumour so as to irradiate every part of it.

As driving force, clockwork or electro-magnetic arrangements may be used.

Subsequent to communicating this paper to the Society, I was so fortunate as to discuss with Mr. E. Haines the best method for carrying out this suggested method in a practical way. Mr. Haines has accomplished all that is required, using an electric drive; and has produced a beautifully smooth-running machine. The mechanically-driven machine is an accomplished fact—thanks to Mr. Haines' ingenuity and resourcefulness.

An entirely different method of providing the requisite driving force occurred to me subsequently to the completion of this first applicator. The object of this new type of drive is to enable the patient to wear the applicator without attachment to any source of mechanical or electro-magnetic power.

The idea is to utilise the respiratory movements of the patient as a source of the small driving power required.

To this end the patient wears a wide belt of a non-elastic material—such as leather. This belt is lined with a light rubber tube, flattened somewhat in cross-section, which is kept rather loosely distended with air. A pneumatic drive affixed to the radiator is connected with this rubber tube. At each respiration of the patient the variation of pneumatic pressure set up in the belt

is conveyed through a light rubber tube to the radiator, keeping this in slow rotation. Absolute steadiness in the movement of the radiator is not essential.

The advantage of an arrangement such as now suggested arises more especially if it is of importance to the patient that he should be able to go about his business or lead an open-air life. The drive would be soft and noiseless. The power required is so little in amount that no sensation of exertion should arise.

No. 4.

PHOTO-ELECTRIC MEASUREMENTS OF ILLUMINATION IN RELATION TO PLANT DISTRIBUTION. PART 4. CHANGES IN THE COLOUR COMPOSITION OF DAYLIGHT IN THE OPEN AND IN SHADED SITUATIONS.

By W. R. G. ATKINS, Sc.D., F.R.S.,
AND
H. H. POOLE, Sc.D.

[Read January 27. Published separately April 24, 1931.]

Introduction.

In previous papers (1929, 1930) descriptions were given of measurements made with portable photometers and galvanometers. In these, sodium or potassium vacuum photo-electric cells were used, since our experiences with a gas-filled caesium cell were unsatisfactory; accordingly, blue light only was measured.

It has long been our desire to study the alteration in the quality of the light. The work of Weisner (1907), Zederbauer (1907), Dorno (1919–28), Klugh (1925), and Burns (1927) has already been referred to by us (1926, 1929).

The aim of this paper is to give the methods which we have used for the photo-electric measurements of the colour composition of light from various sources and in diverse situations, and to discuss their bearing upon plant distribution.

Determination of the Transmission Curves of Light Filters.

In the course of this work a large number of filters were tried. Those listed below were selected from them; where possible glass filters were chosen on account of their suitability for exposure under water and to rain. Of the gelatine* film filters those most stable to light were selected. In this respect, also, the glass filters are usually to be preferred. The transmission of various screens and the sensitivity of different photo-electric cells for different parts of the visible spectrum have been measured by means of a simple form of monochromatic illuminator constructed as follows:—A slit about 0·5 mm. broad is mounted in a lantern containing a "Pointolite" lamp, through which a steady current of

* All were mounted between the makers' B quality glass plates.

1·10 amp. passes, and a suitable condenser. A Grubb portrait lens of about 5 cm. aperture, placed about 25 cm. from the slit, forms an image of it at a distance of about 2·25 m. This image is dispersed into a spectrum, whose visible length is about 15 cm., by means of a large glass prism placed a few centimetres from the lens. All direct light is screened off, and scattered light is reduced to a minimum by blackening all surfaces that might cause reflections, and paying special attention to the polish of the transmitting surfaces. The optical arrangement only differs from that commonly employed in lecture demonstrations to project a spectrum onto a screen in the use of a carefully corrected large-aperture lens and a single large glass prism so as to obtain as much illumination as possible.

The whole optical system is mounted on a substantial turn-table, to which an arm more than 2 m. long is attached to facilitate small rotations. In this way any desired part of the spectrum may be thrown on a window, about 25 mm. by 5 mm., behind which either a thermopile or a photo-electric cell is mounted. The average wave-length of the light passing through this window may be found by noting the position of the image of the slit formed by reflection in the front face of the prism. This forms a convenient index of the exact azimuth of the turn-table. For convenience a second reflecting prism is used, so that the image is formed on a paper scale attached to the laboratory wall in a suitable place. This reflected image is also useful for enabling the lamp to be accurately centred so as to ensure proper illumination of the slit. The scale is calibrated by observing the limits of wave-length of the light passing through the window with a Hilger direct-vision spectroscope. The width of the spectrum band transmitted increases approximately linearly with the wave-length from about 6 mμ at 400 mμ (mean), to about 46 mμ at 700 mμ (mean).

The luminous energy passing through the window is measured by a Moll vacuum thermo-junction placed in the focus of a small lens mounted just behind the window, and forming an image of the illuminated disc of the portrait lens. The junction is much smaller than this image, and is adjusted as nearly as possible centrally in it. The light which misses the thermo-junction on either side is reflected and concentrated by a mirror and another lens into the slit of the Hilger spectroscope so that the wave-length is measured at the same time as the relative energy.

The thermal E.M.F. is measured by a delicate suspended-coil galvanometer made by Kipp, which gives a deflection of 1 mm. at a scale distance of 2·4 m. for a P.D. of about 3×10^{-9} volt. As its resistance is about 24 ohms this represents a current of $1{\cdot}25 \times 10^{-10}$ amp. This scale can be read to 0·1 mm. The sensitivity of the galvanometer is reduced as required towards the red end of the spectrum by means of suitable resistances.

The screen whose transmission is to be measured is inserted between the slit and the portrait lens so that non-luminous radiation from the screen does not reach the thermo-couple, and hence the temperature of the screen is unimportant. Five successive readings are taken—(1) with unscreened radiation, (2) with

radiation transmitted by screen, (3) with radiation entirely cut off, (4) with radiation transmitted by screen, and (5) with unscreened radiation.

As either the transparent or an opaque screen can be inserted by pulling one of two cords the readings can be made at regular intervals of 20 seconds each, which are just long enough to allow the galvanometer to attain its full deflection. By deducting reading (3) from the mean of (1) and (5) the "unscreened" deflection is obtained. Similarly by deducting (3) from the mean of (2) and (4) the "screened" deflection is found, and hence the transmission factor of the screen for the given wave-length. This method of working eliminates, to a great extent, errors due to zero creep, caused by slow variations in the parasitic thermal E.M.F. in the galvanometer circuit.

In plotting the curves shown in fig. 1, a small correction has been introduced, where necessary, for the finite width of the spectrum band employed. The method of correction used is that given in Preston's "Heat." As, however, the corrections are everywhere small, and only become appreciable in regions where rapid alterations occur in the gradient of the curves, they have not been applied in plotting figs. 2 and 3. In these the actual results, as obtained, are plotted without any attempt at "smoothing."

Measurement of the Colour-Sensitivities of Photo-electric cells.

When testing the colour-sensitivity of a photo-electric cell, the latter is substituted for the thermo-couple. In this case the wave-length of the light has to be obtained from the reading of the reflection image, as described above, the relative energy for that band of the spectrum being found from thermo-couple measurements with the same current through the "Pointolite" lamp. The photo-electric current is measured by means of the same galvanometer, which may be shunted, if necessary, in certain parts of the spectrum, or by means of some form of quick-reading electrometer. The latter method was adopted in certain cases, a string electrometer being used, and a revolving shutter driven by a gramophone motor being mounted so as to occult the beam, giving alternate "light" and "dark" periods of about 9 sec. each. The commencement and end of each period was marked by a single stroke of an electric bell, so that the displacement of the electrometer string during the preceding period might be readily noted. The electrometer method was naturally much more sensitive than the galvanometer, but want of uniformity in the electrometer scale, and the need of allowing for leakage currents, made the interpretation of the results more difficult.

It is possible to mount the thermo-couple and the photo-electric cell so that they share the same light, the readings being made simultaneously. This method has the great advantage that their relative readings are not affected by possible errors due to inaccurate re-setting of the projector to the same wave-length, or to changes in the intensity of the source. It, however, obviously reduces the amount of energy available for each, which is a serious drawback near the violet

end of the spectrum. It also entailed the use of the electrometer to measure the photo-electric currents, as a second sensitive galvanometer was not available.

Characteristics of various Filters.

Chance's "daylight" filter is intended to reduce the light of a gas-filled tungsten lamp to daylight quality. Its transmission for a thickness of 2·8 mm. is such that, when combined with type C.M.V. 6 photo-electric cell, it gives a sensitivity—wave-length curve, which is fairly level between 500 and 660 mμ. (See figs. 2 and 3.) It rises, however, in the blue and far red, and transmits infra-red.

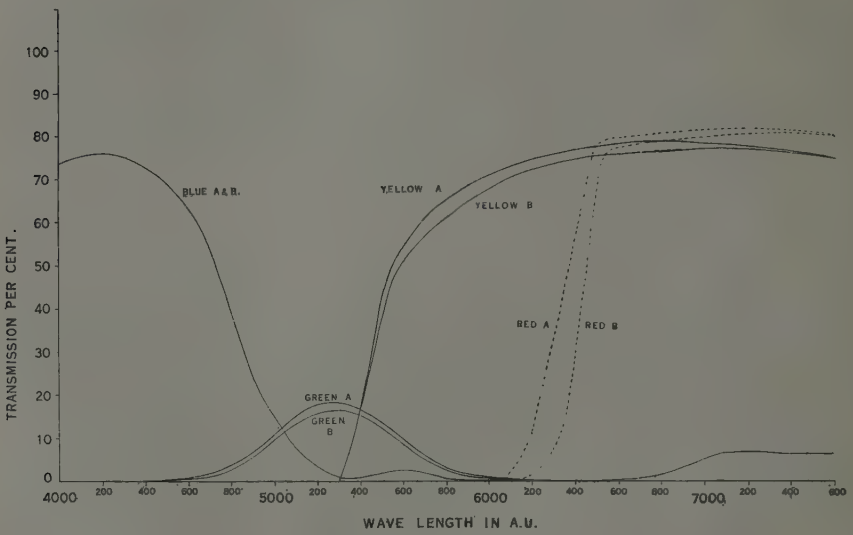

FIG. 1.

Transmission curves for Corning glasses; blue, A and B, each 2·96 mm. thick; green, A 3·47 mm., B 3·81 mm.; yellow, A 2·87 mm., B 2·96 mm.; red, A 3·23 mm., B 3·63 mm. The curve for blue rises again as shown in the deep red, the transmission reaching 14·5 per cent. in the infra-red.

Corning "heat-absorbing glass, G 392 H, medium shade," is made as a protection for films shown by lantern. It is of a greenish colour, and eliminates the infra-red, the red being also heavily cut with the thickness used, 4·2 mm. This reduces the response of C.M.V. 6 to 17 per cent. under conditions of sunshine, blue sky, and some clouds; 4·9 mm. reduces it to 15·3 per cent. For transmission, see figs. 2 and 3. With C.M.V. 6 the 4·2 mm. filter gives a sensibly equal response for equal amounts of energy between 440 and 640 mμ.

In order to avoid reducing the red sensitivity so heavily, thinner specimens of this glass have been obtained, also samples of the "light shade." These, it is

hoped, may reduce the infra-red sufficiently without cutting down the visible radiation quite so heavily.

Corning "dark blue, G 54," marked "H lantern blue," is said to be useful when a pure blue is needed (Gage, 1924). The transmission of 2·90 mm. is shown in fig. 1. Though eliminating the green quite well its red transmission is appreciable, rising to 14·5 per cent. in the infra-red. In view of the sensitiveness of C.M.V. 6 to red and near infra-red, this is serious, and renders the addition of heat-absorbing glass very desirable. Combining it with a red glass and viewing a gas-filled tungsten lamp its red transmission can be seen.

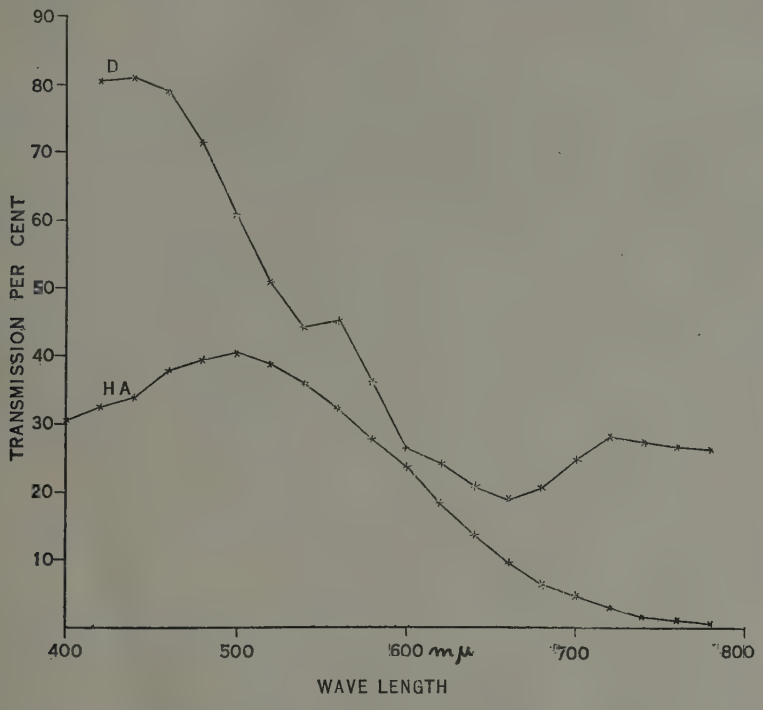

Fig. 2.

Transmission curves for Chance's "daylight" glass (D), 2·8 mm., and for Corning "heat-absorbing" glass (H.A.), 4·2 mm.

Schott and Gen F 22870 B.G. 12, 2·21 mm., is very similar to B.G. 4, a blue glass without infra-red transmission. Tested as above it was found to let no red through. Its transmission curve approximates to the sensitivity curve of a sodium photo-electric cell, whereas that of Corning G 54 is nearer to that of a potassium cell. Chance's blue glass, 3·5 mm., appears to be a pure blue, but the Schott and Gen could be more conveniently used on account of its size, weight and bevelled edges.

Corning "sextant green," 3·81 mm., is a good green, see fig. 1. From its visual examination one would imagine its transmission to be about equal to those of the Corning blue and red glasses described here. It is, however, far lower, but the great sensitivity of the eye for green gives the appearance of equality. It stops the red and near infra-red completely. The somewhat similar glass, Schott and Gen F 22448 V.G. 2, 1 mm., though it transmits between 450 and 650 mμ, has a negligible infra-red transmission up to 1200 mμ.

Wratten No. 62, "mercury green," was chosen for its purity of colour and stability. These gelatine filters are admittedly subject to unavoidable variations in the filter film, the values given in "Wratten Light Filters" (1925) being those for standard filter films. The transmissions for the film we worked with were, however, found to be about twice as great as the values given by the makers. Moreover, nothing is shown in "Light Filters" beyond 700 mμ, whereas we found a very high transmission in the extreme red. Visually the Corning and Wratten greens are very similar. It was surprising, therefore, to find that in absence of direct sunlight the response of C.M.V. 6 was reduced to 2·9 per cent. when the Corning green was interposed, and to 36·5 per cent. only with the Wratten No. 62. These results led us to examine the latter thoroughly, and so to discover the large deep-red and infra-red transmission.

Corning "H.R. yellow, green shade," 2·96 mm., gives a high transmission with a fairly sharp cut-off. This is apparently one of the selenium orange series, as it was sent in answer to an order for G 34. Owing to lack of sensitiveness in the film used the absorption spectra of these Corning orange and red glasses end at 710 mμ, as shown by their clear glass control (Gage, 1924). The transmissions are, however, very high right into the infra-red, hence the necessity for combining them with heat-absorbing glass.

Corning "selenium red," G 24, 3·23 mm., has a very sharp cut-off at about 610 mμ, see fig. 1.

Schott and Gen, List 4213, F 2702, R.G, 5, 1·97 mm., is a dark red, and cuts off sharply at 650 mμ.

In addition the following filters were used on special occasions:—

Pyrex glass, 4·0 mm., a clear glass, faint-green tinge when viewed end on, cuts out ultra-violet, anti-rachitic portion (Luce, 1926).

Wratten No. 25, "tricolour red," very similar to Corning red when used with C.M.V. 6; being glass the Corning red is preferable.

Wratten No. 12, "minus blue," a quite stable yellow; No. 32, "minus green" 3, a moderately stable magenta; No. 65 A, "minus red" 3, a stable green.

Corning didymium glass, 6·7 mm., cuts out the sodium yellow lines, and so is useful in spectroscopy. A wire dipped in sea water and heated in a bunsen flame shows the potassium violet if viewed through this filter. It may be combined with sextant green to give a very pure green. It has been used by Lord Rayleigh (1930) to isolate the auroral green line. It enhances visual red, bringing the tint of normal skin up to that of a marked erythema.

Corning red-purple Corex A, ultra-violet transmission glass, which we have

previously described (1929, 2), was used here for obtaining the ratio of total vertical to diffuse vertical ultra-violet in the open.

A set of varying intensities, $\frac{1}{2}$, $\frac{1}{4}$, etc., of Wratten No. 96, "neutral grey," non-selective in absorption, was used by Stanbury in culture work on diatoms, the supposed values being checked with a sodium cell. They were also used in making a rough visual estimate of the light reflected from leaves.

For detailed descriptions of the Corning glasses, see under Gage (1924) in bibliography, also for Schott and Gen, and Wratten filters, see bibliography. The transmission of some filters, other than those plotted in figs. 1 and 2, are given in Table 1.

TABLE 1.

Percentage transmissions of some light filters: determined by other workers by visual methods, with the exception of W. 62, which was tested by us with the thermopile also, marked W. 62*. B.G. 12 = Schott and Gen B.G. 12, Blue, glass, 2·21 mm. thick; R.G. 5 = Schott and Gen R.G. 5, Dark Red, glass, 1·97 mm. thick; W. 62 = Wratten W. 62, Mercury Green, gelatine.

λ mμ	B.G. 12	λ mμ	W. 62*	W. 62	λ mμ	W. 62*	R.G. 5
400	69·5	480	0·4	—	640	0·0	0·0
420	67·5	490	0·5	—	650	0·0	2·0
440	57·0	500	0·5	—	660	0·0	27
460	35·0	510	7·6	0·3	670	0·0	62
480	13·9	520	21·4	8·0	680	0·3	82
500	4·2	530	26·0	14·7	690	1·7	90
510	0·5	540	19·7	10·9	700	7·9	92
520 to 690	0·0	550	10·9	5·0	720	22·3	93
		560	4·0	1·5	740	45·5	94
700	0·1	570	1·6	0·2	760	73·5	—
760	1·0	580	0·6	—	770	77·5	96
		590	0·3	—			

The Use of Opal Glass as a Diffusing Medium.

As we have already pointed out, the wide variations in the angular distribution of daylight necessitate the use of a diffusing photometer window. For this purpose we have employed a "double surface flashed opalized glass," supplied by Messrs. J. Hetley & Co., London. This glass, contrary to what might be inferred from its name and to what we have previously reported, is flashed on one surface only. It combines excellent diffusing properties with a high transmission, which is approximately non-selective throughout the visible spectrum.

It is evidently not possible to use the thermo-couple method to measure the colour transmission of the opal glass, as its diffusing properties would entirely upset the optical arrangements, and the transmission recorded by the couple would be close to zero. If the lens used for concentrating the light onto the thermo-junction were eliminated, and the opal interposed immediately in front of the couple, the resulting current would be so affected by invisible radiation from the opal, depending on the varying temperature of the latter, that the readings would be valueless as a measure of the luminous energy transmitted. This sensitivity of the thermo-couple to invisible radiation from bodies at ordinary temperatures is the chief obstacle to its use for the measurement of daylight.

To test the transmission of the opal a photo-electric cell must be used, readings being taken alternately with and without the opal, which is interposed immediately in front of the cell.

The results will give relative transmission for different wave-lengths, but not the effective transmission factor for an opal window in front of a cell used for the measurement of daylight, since neither the whole area of the opal window nor, when the opal is removed, the whole area of the pupil of the cell is illuminated by the monochromatic beam. In measuring daylight one generally uses an opal window considerably larger than the pupil of the cell, whereas in the colour test the illuminated area is usually smaller than the pupil.

Tests carried out by this method with a sodium photo-electric cell indicated that the transmission factor of the opal increased from about 48 per cent. at 390 mμ to about 54 per cent. at 460 mμ. In this case the cell was permanently mounted behind an opal window, so the figures refer to the transmission of a second opal which was alternately inserted and removed.

Less accurate measurements were obtained by comparing the sensitivity curves for some other cells obtained with and without opal windows, respectively. In this case one is trusting to accurate re-setting of the projector and constant emission of the source in comparing the "opal off" and "opal on" values for the same nominal wave-length. The results with a Burt sodium cell indicated a rise of transmission from 40 per cent. at 390 mμ to 50 per cent. at 460 mμ. These figures are not comparable with the preceding ones, as a second opal was not used, and hence the effect of scattering was quite different, but agree with them in showing an appreciable fall in transmission in the extreme violet and near ultra-violet. For longer wave-lengths a sodium cell is unsuitable, and the only figures available were obtained with the red-sensitive cell type K.M. 2 (see fig. 3). The tests were not, in all respects, very satisfactory, but showed clearly that from 460 mμ to the red end of the visible spectrum the variation in transmission of the opal was small compared with the variation in sensitivity of the cell.

As the use of bare photo-electric cells to measure daylight often results in large errors (depending on the particular cell used), due to the varying altitude and azimuth of the average illumination, the cell should always be exposed under an opal, and hence the colour-sensitivity of the bare cell is of secondary

importance. Our usual practice, therefore, has been to test the colour-sensitivity of the cells behind opal glass. We feel, however, that more accurate tests on the selective transmission of the opal are desirable, and hope to carry them out in the near future.

Table 2 shows the effect of placing a sheet of opal glass over a Burt sodium vacuum cell. This cell has a relatively large pupil, and the effective transmission factor of the opal shows a total range of some 20 per cent., attributable chiefly to anomalous readings of the bare cell for light of varying altitude and azimuth. It is probable that with other cells, and with low-angle sunlight, larger variations would occur. The figures in the last line were obtained under water with a gas-filled potassium cell. The water reduces the reflection losses at the surfaces of opal glass.

TABLE 2.

Transmission factor of opal glass as determined for daylight by means of a Burt sodium vacuum cell. The loss includes that due to reflection, true absorption, and scattering. The vertical illumination, V, in thousands of metre candles (k.m.c.), and β, the ratio of total vertical to vertical diffuse light, were determined with opal on. α is the approximate altitude of the sun. The figures in the last line were obtained with a gas-filled potassium cell.

Date.	G.M.T.	Conditions.	α.	β.	V.	Transmission Factor.
					k.m.c.	per cent.
June 19th	12.18	Sun clear, blue sky, light haze, a few light clouds.	63°	3·21	93·2	53·8
	2.30	Sun through high white haze, sky white in W., blue in E.	59°	2·21	82·3	46·4
„ 20th.	11.15	Grey sky	—	1·00	29·0	45·1
„ 21st.	11.30	Sun clear, blue sky, light clouds.	61°	3·02	97·2	54·1
„ 26th.	11.55	Sun clear, blue sky ...	62°	3·53	95·2	52·9
Oct. 15th.	3.44	In the sea at 35 metres depth	—	1·00	0·78	55·6

Measurement of the Photo-electric Current.

For the measurement of the current through the red-sensitive cell, C.M.V. 6, with colour filters, the portable Onwood micro-ammeter No. 3,140, which could be read to 0·02 μa, was sufficiently sensitive only in the open. It was, accordingly, necessary to use Onwood No. 3,063 (see Table 2, 1929). This was mounted in a light-tight case, with a scale at one metre distance, fitted with a drawband to release, or clamp, the galvanometer without opening. It has a point support

at one end and two levelling screws at the other, and contains a four-volt lamp. The current per scale division at 1 metre was $1{\cdot}85 \times 10^{-9}$ amp. The deflection may be doubled by a reversing switch. The case is easily carried, having a leather strap. The weight is 8·5 kg., and a 4-volt dry battery weighing at least 0·3 kg. is also required.

The drawback to the large galvanometer case is not its weight, nor even its size, but its liability to disturbance in a wind, and also the difficulty of levelling it on the rough ground in most of the woodland sites studied. During the measurements recorded here, for Antony, it was placed on a table in a room with a stone floor. It could not be used in a room with a wooden floor. Long leads of high-tension ignition cable were run out into the garden, and connected to the 18 m. leads of the cell, so as to allow of the exploration of shaded sites.

The measurements on September 25th, 1929, and all the 1930 measurements in Devon and Cornwall, were made using the neon lamp device described by J. H. J. Poole (1928), as modified by J. H. J. Poole and H. H. Poole (1930). In this a set of condensers, 0·0005 to 0·5μF., is fixed so that connections can be made by a wander plug to the appropriate capacity. In parallel with the condenser is a well-insulated neon lamp, each partial discharge through the lamp producing a red flash. If the current passing through the photo-electric cell is used to charge the condenser, the rate of flashing of the lamp has been shown by J. H. J. Poole to be proportional to this current, and hence, if a vacuum cell is used, to the illumination falling on the latter. As a voltage of from 130 to 170 (depending on the type of neon lamp used) is required to cause flashing, and an additional potential is needed across the cell sufficiently high to ensure that the sensitivity of the latter is only slightly affected by small changes of pressure, a total voltage of about 240 must be provided.

It is evident that any leakage in the condenser or neon bulb will prevent flashing for all charging currents smaller than a certain minimum, and will cause a corresponding error in the measurement of larger currents. To prevent the possibility of such unknown errors being caused by surface leaks under damp conditions, the neon bulb, whose terminals are at opposite ends, is coated with paraffin wax, and a set of guard rings are provided and maintained at a potential of 170 volts. With this arrangement any surface leaks will cause flashing with the cell dark. Such "dark currents" can readily be detected and allowed for, if necessary. With the guard rings disconnected it was found that flashing might not occur with illuminations below 200 or 300 m.c. This error would be of little importance in full daylight, but would be very serious in shaded sites. With the guard rings connected, very small illuminations may be measured if any small "dark currents" are allowed for.

The weight of the neon lamp outfit, with two stop-watches and cardboard case with strap, is 4·4 kg. Four 66 v. dry batteries with box, strap and connections amount to 9·7 kg., total 14·1 kg., or with C.M.V. 6 and its 18 m. of double cable and light-filters (1·8 kg.) and fibre case (1·5 kg.) a total of 17·4 kg.

Thus we have the following weights of field outfits, including the necessary cases :—

For Work in Open.
Micro-ammeter, sodium photometer ... ... 6·2 kg.

For Work in Shaded Sites.
Do. (See Pt. 3, 1930) ... ... 11·5 kg.

For Colour Work in Shaded Sites.
Red-sensitive cell, filters, &c., and large Onwood galvanometer ... ... 14·0 kg.

For Colour Work in Shaded Sites.
Poole neon lamp outfit, red-sensitive cell, filters, &c. 17·4 kg.

All our experience over rough ground has been in favour of the neon lamp outfit for colour work. In practice it is better to put two of the H.T. batteries in the fibre case while walking, and to sling the battery box with two batteries only over the shoulder. One person can carry the whole, taking the lamp box and fibre case one in each hand.

Red-sensitive and other Cells.

One of N. R. Campbell's (1928) red-sensitive cells was obtained, the sensitive surface being a thin-film potassium on oxidised copper type K.M. This was exchanged for one, type K.M. 2, with a palladium side tube, to admit of the renewal of the hydrogen, the absorption of which was found to lead to a loss of red sensitivity. The sensitivity curve for this cell (with opal diffusing glass) is shown in fig. 3. It had been in our possession about four months without renewal of hydrogen. About a year later it had lost its red sensitivity, and behaved much as an ordinary potassium cell, as was shown by its sensitivity to the light transmitted by various filters.

In its red-sensitive condition it would probably have proved suitable for the present research, but our object was to extend the work on land to similar submarine measurements. For this the opening of the photometer to renew the hydrogen would have constituted a serious drawback.

The absence of infra-red sensitivity and the relatively high green sensitivity are points in favour of this cell as compared with C.M.V. 6, mentioned later. When mounted under opal and standardized against an open carbon arc lamp according to our usual method it was found to give 10^{-9} amp. per 6 metre candles with anode potential 120 volts. The window was 3 cm. in diameter, as in our submarine photometers, but as it is a large cell the sensitivity could probably be doubled by increasing the aperture.

The voltage characteristic, up to 120 volts, resembles that of a vacuum cell, comparatively large variations in anode potential having little effect at high voltages. This would render it suitable for use with the neon lamp outfit.

The current was found to be nearly proportional to the light up to 140,000 metre candles at 120 volts anode potential. The cell appeared to stand this illumination, equivalent to full sunlight, perfectly well, and with it gave a current of about 19 micro-amperes.

Through the courtesy of the General Electric Company we were, however, supplied with Dr. N. R. Campbell's new red-sensitive cell, type C.M.V. 6, a

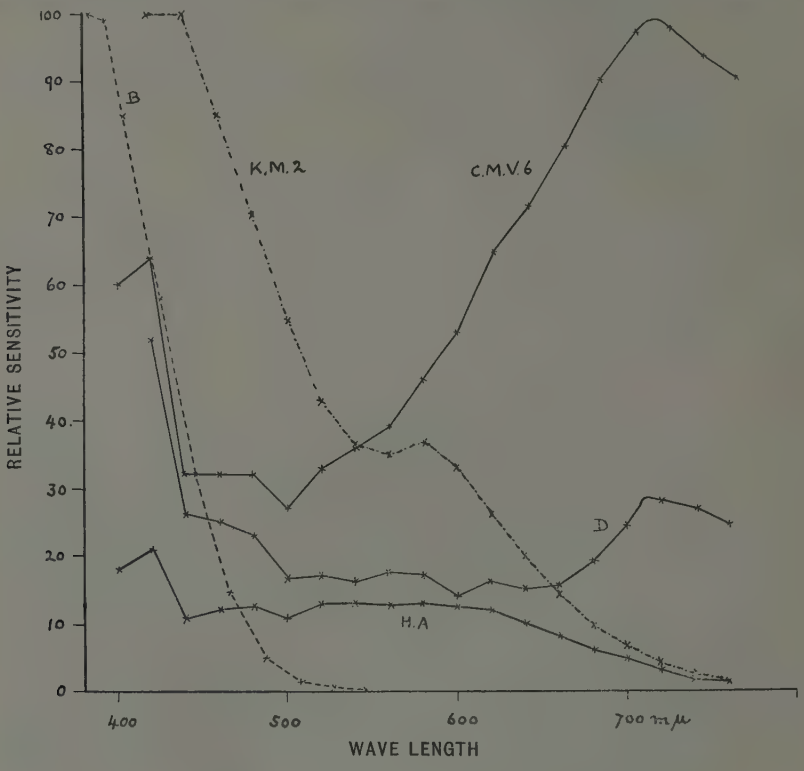

Fig. 3.

Sensitivity curves of Burt sodium (B), Campbell thin-film potassium (K.M. 2), and Campbell thin-film, caesium (C.M.V. 6) photo-electric cells mounted under opal glass. The curves marked D and H.A give the sensitivity of C.M.V. 6 (with opal) mounted under "daylight" and "heat-absorbing" glasses, respectively.

thin-film caesium on silver vacuum cell (see type C, frontispiece, Campbell and Ritchie, 1929). The sensitivity of these thin-film cells seems to resemble those shown in Campbell and Ritchie, fig. 7, but we determined the curve for the actual cell we used, as variations occur (see fig. 3). It was mounted under opal glass. There is a well marked maximum in the red at about 710 mμ and a minimum at about 500 mμ. At shorter wave-lengths the sensitivity again rises

somewhat. It will be noticed that the cell is also sensitive to the infra-red, although the curve falls somewhat sharply beyond the visible spectrum. It is, accordingly, important to use only such colour filters for the shorter wave-lengths as are free from an appreciable transmission in the red, or infra-red, if it is desired to measure only visible radiation.

When mounted behind opal glass and standardized against a carbon arc C.M.V. 6 gave almost exactly 10^{-9} amp. per metre candle with anode potential 62 volts.

Figure 3, which shows the wave-length-sensitivity curve of our No. 1, C.M.V. 6 type cell, mounted under opal glass, gives also (D) the sensitivity obtained when combined with Chance's daylight filter. The curve rises towards the ends and continues into the infra-red.

The curve marked H.A. is that for C.M.V. 6 mounted under both opal and Corning heat-absorbing glass. Between 440 and 640 mμ the response for equal amounts of energy is very approximately the same.

Curve B represents a Burt sodium vacuum cell (No. 299) with opal screen. This is said to have a maximum at about 360 mμ, but our measurements did not go beyond 384 mμ. Its region of greatest sensitivity is obviously for far shorter wave-lengths than the potassium cell, and totally different from that of C.M.V. 6. It may be added that its sensitivity around 450 and 500 mμ is well below that of a G.E.C. sodium vacuum cell previously examined by us without opal filter (1928, fig. 2). The latter showed a relative sensitivity of 50 per cent. at 450 mμ, 18 at 500 mμ, 5 at 550 mμ, and about 1 at 600 mμ. It seems probable that the electrolytically deposited sodium in the Burt type is of great purity, and that traces of other metals may appreciably modify the form of the curve. In fact we have found even potassium cells from the same source may differ among themselves somewhat. This is a common experience.

Owing to the difference between the sensitivity curves for the Burt sodium cells and for the potassium cells we had previously used for daylight in submarine measurements, it is evident that to standardize the sodium cell against a carbon arc and use it to measure daylight would involve the adoption of an entirely new scale. A third scale of values would be obtained if we used the red-sensitive C.M.V. 6 as a basis of comparison. Although this would approximate much more closely to the visual one, it seemed better, for the present, to retain our original potassium scale, i.e., to standardize the potassium cell photometer against the arc, as before, and to rate the sodium cell, or the C.M.V. 6 cell as the case may be, in metre candles per micro-ampere by standardization in full daylight, including sunlight, against the potassium cell, both being mounted under opal glass.

Determinations of β, the ratio of total vertical to diffuse vertical illumination, were found to be very much the same with the sodium and potassium cells, the former being rather smaller on the whole; the data are presented further on. This is what might be expected, since diffuse daylight is generally bluer than direct sunlight.

Before adopting a new scale for daylight measurements, to replace the potassium scale, it is desirable to choose, as a standard, a photometer with a suitable wave-length—sensitivity curve. This has been our object in making use of the combination of various filters with type C.M.V. 6. Our aim has been to cut out the infra-red, which is believed to be ineffective as regards photo-synthesis, and—if possible—to get a response with the cell which is the same for equal amounts of energy, irrespective of wave-lengths, throughout, at least, the spectral region concerned in photosynthesis. The combination with heat-absorbing glass is a tolerably good approach to this. The light, thus filtered, would give a true energy reading throughout the day even if its colour were to alter, as it is known to do, and as will be shown further on.

This aim is quite different from that of those who wish to record light as it affects the human eye. Thus Dorno (1924), Aurén (1930), and Harrison (1930) use various yellow filters to make the sensitivity curves of their cells as close as possible to that of the normal human eye. Since this curve is quite different from that relating wave-length to quantum efficiency in photo-synthesis (Warburg and Negelein, 1923), we have thought it better to aim at a record of the energy received.

Comparison of Red-sensitive and Sodium Photo-electric Cells.

It has been our practice for some years to cross-check our cells in daylight and to test potassium cells, standardized in metre candles against an electric arc, with a test lamp reserved for the purpose (1928). The potassium and sodium vacuum cells have remained remarkably constant. Campbell's newer type of red-sensitive cell, C.M.V. 6, also appears to possess great stability, perhaps even greater than the other cells mentioned, and this in spite of the instability of the ordinary caesium cells, associated with the relatively high vapour pressure of the metal. During manufacture it is baked at a high temperature, so that one need not fear to expose it freely to the sun. For a given sensitive area, its sensitivity in daylight is far greater than that of the Burt cells. When compared with a Burt cell having a much larger sensitive area exposed, the results shown in Table 3 were obtained.

The values shown in Section B of the Table were calculated from comparison with our most sensitive Burt cell (No. 223).

Naturally, under different lighting conditions, the ratio varies, as the sodium cell is relatively more sensitive to blue sky light than to sunlight. But, as such a predominantly red-sensitive cell and a blue-sensitive cell show no greater difference under such diverse conditions, it seems allowable to conclude that no very serious error will be committed in taking either of them to record daylight, especially as the values for grey sky and for mixed sunlight and blue sky agree so well. It must be remembered, however, that C.M.V. 6 is sensitive to infra-red also, and that the sodium cell is most sensitive to ultra-violet. It may be seen

from the Table that the actual illuminations measured show a seventy-fold variation, 55·4 to 0·78 k.m.c.

TABLE 3.

Comparison of red-sensitive and sodium photo-electric cells in daylight. V is the total vertical illumination as found by the sodium cell standardized in daylight against a potassium cell, and V' the total vertical illumination as found by C.M.V. 6 standardized against the arc. The ratio V'/V illustrates the difference between the potassium and thin-film caesium scales for various types of daylight. *A*, September 18th, 1929, on roof of Marine Laboratory, Plymouth. *B*, September 19th, 1929, garden lawn at Antony. *C*, September 24th, 1929, on lawn, no direct sunlight. Values of β with sodium cell.

	G.M.T.	α	β	V k.m.c.	V' k.m.c.	V'/V
A.						
Blue sky, clouds and weak sunlight ...	12.15	42	1·12*	41·7	22·3	0·535
Blue sky, some clouds, sun clear	2.0	36	2·31†	55·4	29·4	0·53
Do. do.	2.50	31	2·27	44·2	22·2	0·505
B.						
Grey sky	1.35	—	1·00	35·0	16·6	0·475
	2.15	—	1·00	27·9	13·2	0·475
C.						
Blue sky, some clouds, no direct sun on photometers.	5.0	—	(c. 1·2)	3·05	1·05	0·345
Do. do.	5.40	—	(c. 1·1)	1·38	0·525	0·38
Low haze, clouds pink, sunset	5.50	—	(c. 1·0)	0·78	0·28	0·36

* With C.M.V. 6, $\beta = 1·29$ just before. † With C.M.V. 6, $\beta = 3·45$.

The Use of Light Filters.

When a filter is placed over a photo-electric photometer, the current through the latter is reduced to a percentage of its previous value. We may, for convenience, call this percentage the "transmission factor" of the filter for the particular conditions involved. This factor depends on (*a*) the wave-length—transmission curve of the filter, (*b*) the wave-length—sensitivity curve of the photometer, (*c*) the spectral distribution, *i.e.* the colour, of the incident light, (*d*) the obliquity—sensitivity curve of the photometer, and (*e*) the angular distribution of the incident light.

Neglecting, for the present, the effect of obliquity, which will be discussed later, we see that the transmission factor of a given filter, whose wave-length—transmission curve is known, may be used with a constant illumination to obtain data as to the colour sensitivities of various cells. Alternatively, if we use a cell of sufficient colour-range of sensitivity, we may by the use of filters obtain information as to the colour of the illumination under different conditions.

An example of the first application is given in Table 4, which shows how the transmission factors of various filters depend on the type of cell employed, and hence indicate the relative sensitivities of the cells to the different colours transmitted by the filters. Since these cells were all mounted under opal glass, we are not concerned here with the transmission of the short-wave solar ultra-violet; upon this we hope to present data elsewhere.

It may be seen that the reflection losses due to the interposition of the untinted glasses come out close to the theoretical value (4 per cent. of the normally incident light being lost at each surface) for light incident normally, though the mean angle of altitude of sky light plus sunlight was probably near 50° or even less.

Inspection of the Table brings out the suitability of C.M.V. 6 for measuring red and blue light, also its lack of good sensitivity in the green, especially as the green filter absorbs very heavily. It is curious that the banded absorption of the didymium screen should result in the same percentage response with three cells—two types really, as K.M. 2 had stood for so long that it had lost its red sensitivity.

TABLE 4.

Transmission factors of various filters as recorded by sodium, potassium, thin-film potassium (K.M. 2), and thin-film caesium (C.M.V. 6) cells, mounted under opal glass. Comparisons made in open situations, with sun, blue sky, and clouds. V = 90–106 k.m.c. and β 3·1–3·5 for all save C.M.V. 6, where V = 60 k.m.c. approx. and β 1·9 for blue light. P = polished, S = smooth, C = uneven.

Filter.	mm.	Surface.	Transmission Factor. Na.	K.	K.M. 2.*	C.M.V. 6.
Heat absorbing	4·2	C	—	27·7	29·8	17·0
„ „	4·9	C	27·5	24·6	—	15·3
Corning blue	2·9	P	—	53·5	53·5	23·4
„ green	3·8	P	—	3·2	2·3	2·6
„ yellow	2·9	P	—	3·0	2·3	36·3
„ red	3·2	P	—	0·4	0·2	35·9
W. tricolor red	—	P	—	0·4	—	36·1
W. minus green	—	P	—	41·6	—	54·4
Didymium	6·7	C	—	44·6	44·2	44·4
Pyrex glass	4·0	S	—	91·7	91·7	—
Photographic plate ...	1·7	S	92·2	91·6	90·5	—
Vitaglass, clear	2·7	S	92·2	92·2	90·5	—
„ "cathedral" ...	4·2	C	89·2	87·0	85·2	—

* After prolonged standing, without renewal of hydrogen.

Measurements of the Colour of Daylight.

If we employ a single cell, such as C.M.V. 6, we can, as already pointed out, use the transmission factors of various filters as an index of the colour of the light on different occasions. Thus, during the afternoon of September 24th, 1929, the transmission factor for the Corning red filter, as determined by C.M.V. 6 cell behind opal glass, for the diffused light from a blue sky with a few clouds, was 21·7 per cent. at 3.15 p.m., 23·7 per cent. at 3.45 p.m., 21·6 per cent. at 4.25 p.m., and 30·8 per cent. shortly after sunset, when there were low clouds tinged with pink. The increase in the percentage of red light is clearly indicated.

We have already (1930, 2) described some measurements on the colour of daylight made by this method, but, as it is an essential part of the present paper, it is here considered more fully.

Table 5 shows how the transmission factors for the various colours vary with the colour of the light. Attention may especially be drawn to the high percentage of blue in sky light, of green in deep shade under Taxus, and of red in the light of a gas-filled lamp, especially if the voltage be reduced.

TABLE 5.

Transmission factors of Corning filters as recorded by C.M.V. 6 type cell for light from various sources. β and δ are for blue light. Observations on September 18 at Plymouth, September 24 at Antony, Cornwall, on May 26 at Dublin.

Light, source, and conditions.	Blue.	Green.	Yellow.	Red.
Sept. 18, forenoon, sun and blue sky with clouds, V = 60 k.m.c., α = 40°, β = 1·9.	23·4	2·6	36·3	35·9
„ 2.30 G.M.T., sun and sky as above, α = 33°.	—	2·9	35·8	30·8
Sept. 24, 3.45–4.0 G.M.T., blue sky light only ...	30·0	2·9	27·4	23·7
„ 1.15 G.M.T., deep shade under Taxus, δ = 0·9 per cent.	23·0	12·0	52·7	55·8
May 26, noon, sun and hazy blue sky, ... V = 100 k.m.c., α = 58°, β = 2·28.	20·6	—	45·8	37·8
„ blue sky light alone	34·0	—	29·6	22·2
„ sunlight alone (by differences) ...	16·2	—	51·2	42·8
Motor head lamp, gas filled, run at 10·0 volts, normal incidence.	6·9	1·25	73·4	72·0
Motor head lamp, gas filled, run at 11·0 volts, normal incidence.	7·0	1·34	72·5	70·6
Motor head lamp, gas filled, run at 12·0 volts, normal incidence.	7·1	1·46	71·4	69·7
Carbon arc lamp, normal incidence	12	2·0	61	56
Carbon arc lamp, 45° incidence	11	2·0	58	55
Ratio, 45° to normal	0·92	1·00	0·95	0·98

While the figures in this Table indicate clearly the colour differences of various types of illumination, they do not give a very convenient measure of these differences. If, however, we decide to regard as "white," *i.e.* as standard, any given type of illumination, we can find ratios green/blue, yellow/blue, and red/blue for this illumination, and also for any other illumination whose colour we wish to specify. The ratio green/blue for the given illumination to green/blue for the standard may be called the "Colour Factor" of the given illumination for the green filter, and so on. The blue screen has been taken as a standard, since all our previous work has been done with blue-sensitive cells, whose sensitivity curves approximated to that of the C.M.V. 6 cell combined with the blue filter.

As an example, the ratios for the blue sky light on September 24th are green/blue, 0·097; yellow/blue, 0·913; and red/blue, 0·790; while, for mixed sunlight and sky light on September 18th, we have green/blue, 0·111; yellow/blue, 1·55; and red/blue, 1·535. If we take the blue sky light as a standard, we get the following figures for the colour factors of the mixed light: — green, 0·111/0·097 = 1·15; yellow, 1·55/0·913 = 1·70; and red, 1·535/0·79 = 1·94.

It will be seen that for the light chosen as a standard the colour factor for every screen is, by definition, unity, and the magnitude of the factor for any other illumination is a direct measure of the relative intensity of the corresponding colour, blue being always taken as unity. We have already shown that the illumination in most shaded sites depends almost entirely on the diffuse daylight only, so, in determining the changes of colour occurring in a wood, it is generally best to take the diffuse light outside it as standard, the direct sun being screened off. This diffuse light in the open will itself vary somewhat in colour according as the sky is clear or clouded, but corresponding changes will occur in the colour at the shaded site. So, by taking as standard the light in the open at the given time, we shall obtain values for the colour factors at a given site, which, like the daylight factor, are characteristic of the site.

We have already defined the "Daylight Factor," δ, as the ratio of the illumination at the site to the diffuse illumination in the open. This ratio, which is most conveniently expressed as a percentage, refers in our previous work to blue light only, our measurements having been made with blue-sensitive cells. It is easily seen that the daylight factor for any other colour is equal to the daylight factor for blue multiplied by the colour factor, since the colour factors for all colours are each unity, by definition, for the light in the open.

How little a woodland site is affected by direct sunlight was shown in our first paper of this series (1926, Table 5, Site B). At 11.55 in the open with $\beta = 3·1$, $V_0 = 81{,}500$ m.c., and in the wood $V_s = 4{,}770$, giving δ, as found for diffuse light only, 18·1. At 11.59, with clouds over the sun, $\beta = 1·0$, $V_0 = 25{,}400$ m.c., and $V_s = 4{,}630$, giving $\delta = 18·3$. At 12.1, with sun out again, $\beta = 3·0$, $V_0 = 76{,}700$, and $V_s = 5{,}310$, giving $\delta = 20·7$.

It is evident that in determining colour factors it is not necessary to take readings of the unscreened photometers, since we are only concerned with the ratios of the various colours to each other. If, however, we desire to measure the total light, we must make observations without colour filters, as it is evident that the colour factors as defined above are not additive. For example, the light transmitted by the yellow filter includes the red.

Effect of Obliquity on the Transmission of Screens.

The figures in the lowest three lines of Table 5 show the effect of obliquity of incident light on the transmission factors of the screens. Three of the four screens transmitted a smaller percentage for oblique than for direct light, but the differences, which, of course, are due to the greater thickness of screen traversed by the oblique light, are smaller than one would expect, and in the case of the green screen could not be detected. With the light at 45°, the current without the screens was reduced to 0·655 of its normal value. This is a few per cent. smaller than the ratio 0·695 to be expected theoretically after allowing for the enhanced reflection loss, the discrepancy being probably due to variations in the arc.

The calculated effects of obliquity on the transmission of four screens whose transmission factors for perpendicular monochromatic light are 10, 1, 0·1, and 0·01 per cent., respectively, are plotted in fig. 4. The refractive index of the screens is assumed to be 1·51 in calculating the effective relative thickness for oblique light, and allowance is made for the reflection losses at both surfaces* by means of Fresnel's formulae. For perfectly non-selective screens these curves would apply to light of any wave-length, and hence to polychromatic light of any spectral distribution. With coloured screens, however, the effect is very different. For those parts of the spectrum which the screen transmits freely the added absorption due to obliquity is comparatively small, while for regions in which it is more opaque the obliquity effect is more important.

Thus obliquity enhances the selectivity of the screen, while its effect in reducing the fraction of the total polychromatic light transmitted is much less important for a coloured than for a neutral screen. This can be most readily seen by considering an ideal extreme case—a screen which has 100 per cent. transmission for one part of the spectrum and is opaque to all other light. Such a screen might transmit any fraction of the total luminous energy in daylight, depending on the width of the transmission band, but the effect of obliquity on this transmission factor would be nil. Reflection losses are assumed to be zero for this ideal screen.

With a diffuse light source, such as the sky, the matter becomes somewhat complicated. The vertical illumination due to a uniform sky, as measured by a

* In the case of gelatine filters the surfaces separating the film from the protecting glass plates above and below may be neglected, since the film is in optical contact with the glass and the similarity of their refractive indices renders the reflection loss inappreciable.

photometer with a horizontal diffusing window, is half the total illumination, *i.e.* it is the same as would be produced by a beam equal in intensity to the entire sky light making an angle of 30° with the horizon. The factor 1·06, which corrects for the effect of obliquity on the reflection loss at the surface of the photometer window, is also the same in both cases. When, however, a screen is interposed, the light from any given small area of the sky is reduced

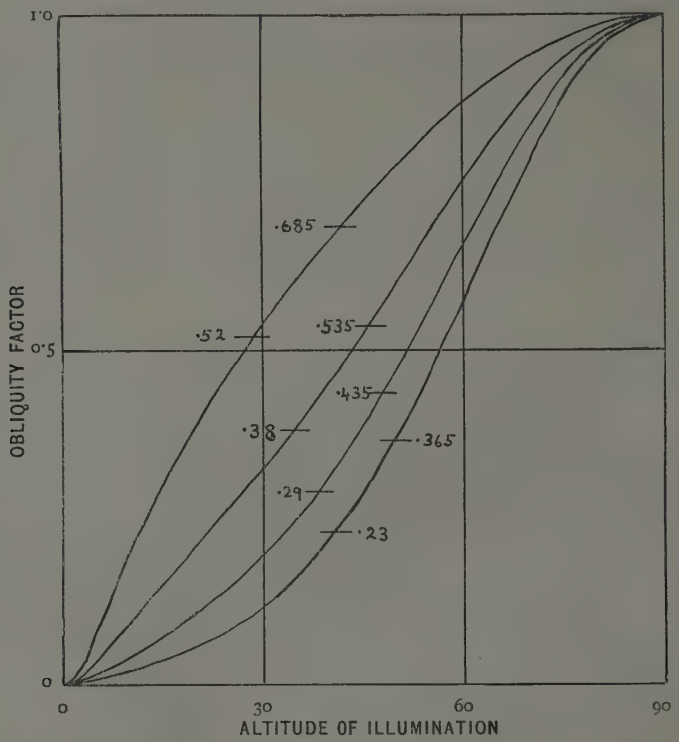

FIG. 4.

Effect of obliquity on the transmission factors of screens for monochromatic light. The "obliquity factor" is that by which the normal transmission factor must be multiplied to obtain the transmission factor for oblique light. The upper curve represents a screen whose transmission factor for vertical light is 10 per cent.; the remaining curves (in order) represent screens whose normal factors are 1, 0·1, and 0·01 per cent., respectively. The marked ordinates give the factors for diffuse light, as explained in the text.

by the screen to an extent depending on the altitude of the area (see fig. 4) and on the refractive index of the screen which also affects the length of light path through the latter. As a result high-angle light penetrates the screen more freely than low-angle light, and the average altitude of the transmitted light is greater than that of the incident.

Two ordinates are marked on each of the curves in fig. 4, the lower one on each curve indicating the obliquity factor for the total light from a uniform sky, and the upper, that for the vertical component of this light. Thus, for example, from the first curve we see that a screen which transmits 10 per cent. for normal light will transmit $10 \times 0{\cdot}52 = 5{\cdot}2$ per cent. of the total light from a uniform sky; but, as this transmitted light is, on the average, at a higher angle than the incident sky light, it is more effective in contributing to the vertical illumination, and so the transmission factor for the latter comes out as 6·85 per cent.

It is evident that the effects of obliquity will introduce some errors into many of the colour factor determinations given in this paper, but these are not likely to be important. In the later determinations, an improvement was effected by placing the opal glass over, instead of under, the filter. This gave an almost uniform angular distribution to the light entering the filter, and so rendered its transmission curve independent of the obliquity of the daylight. The curve must, however, differ appreciably from that for normal incidence, as determined experimentally, and must depend somewhat on the obliquity-sensitivity curve of the bare cell which is exposed below the filter.

The ideal arrangement would seem to involve the use of two opals, one above and one below the filter, so as to cut out irregularities due to both obliquity of illumination and anomalous angular sensitivity of the cell. This would, however, involve too great a loss of light for work in shaded sites. Moreover, anomalies in the angular sensitivity of a given cell are, at least, constant, and their effects on the transmission factor are probably not very important, so that it seems best for most purposes to use a single opal placed over the filter.

Colour Factors of Various Types of Illumination.

Table 6 shows the colour factors obtained, as described above, from measurements made on various occasions. Some of these have already been given in Table 5.

It will be seen that with the sun shining and a blue sky the colour of the light may be quite similar to that from a grey sky, which is here taken as standard. On the other hand, the great difference between the separate effects of sunlight and blue sky light is clearly shown. This point is further discussed later. In one rather curious case, September 3rd, 1930, we found an afternoon sky, including sunlight, relatively very rich in green.

Again, under trees—in heavy shade—the green is much increased and the blue decreased relatively to yellow and red.

The records at the bottom of the Table show how different the light of a gas-filled tungsten lamp is from daylight and even from sunlight. As the voltage is increased the colour of the light tends to get whiter.

This difference in colour composition between gas-filled tungsten lamps and daylight was the reason we avoided standardizing our photo-electric cells against

these lamps and chose instead to standardize against the carbon arc. This, it may be seen, does not differ from sunlight in colour composition to anything like the same extent. We are, however, making an attempt to standardize in metre candles of "mean noon sunlight" produced according to the method recommended for the purpose by the Seventh International Congress of Photography.

TABLE 6.

Colour factors as found by C.M.V. 6 cell and opal glass for Corning filters (over opal). The grey sky light on September 19 is here taken as standard.

Date.	G. M. T.	Place and Conditions.	Colour Factors (Blue = unity).		
			Green.	Yellow.	Red.
1929.					
Sept. 18	10.40–11.45	Laboratory roof, Plymouth, sun ($\alpha = 40°$), and blue sky	1·00	1·00	0·95
,, 19	1.50–2.15	Antony, on lawn, grey sky, sun obscured ...	1·00	1·00	1·00
,, 24	1.20–1.50	Antony, under Taxus, $\delta = 0·9$ %	4·73	1·48	1·50
,, 24	3.45–4.0	Antony, on lawn, sun behind trees, blue sky, clouds	0·88	0·59	0·49
,, 25	2.50–3.15	Do.	1·00	0·68	0·55
,, 25	10.50–11.35	Antony, shade from *Q. robur* and hedge of Aucuba, $\delta = 8$ %	1·00	1·25	1·16
1930.					
May 26	12.20–12.30	Roof of Royal Dublin Society Laboratory, sun ($\alpha = 58°$), blue sky	—	1·43	1·11
		Do., blue sky alone	—	0·56	0·41
		Do., sunlight alone, by differences	—	2·04	1·64
Sept. 3	4.50	Hill-top, Bickleigh, sun ($\alpha = 19°$), blue sky, and many white clouds	2·82	1·38	0·95
		(*Repeated*)	2·27	—	—
,, ,,	2.20	In wood, pure *Picea excelsa*, blue sky, clouds, $\delta = 0·8$ %	5·48	1·27	1·15
		(*Repeated*)	5·51	—	—
		Carbon arc lamp	1·52	3·28	2·90
		Motor head-lamp, gas filled, 10·0 volts ...	1·64	6·85	6·45
		Do. 11·0 ,, ...	1·75	6·65	6·28
		Do. 12·0 ,, ...	1·87	6·49	6·07

Certain of the results of Table 6 are shown in fig. 5; the colour factors for the light filters are plotted for abscissae, which would approximately bisect the area of the wave-length transmission curve within the visible portion of the spectrum. A small allowance, probably an under-estimate, has been made for the effect of the infra-red, blue being taken as 440 mμ, green as 526 mμ, but yellow as 660 mμ instead of 640, and red as 690 mμ instead of 666, since C.M.V. 6 responds to infra-red, and no heat-absorbing screen was used in this series.

Later Measurements Eliminating the Effect of Infra-Red Light.

In the work already described the blue filter used transmitted a little red, just where C.M.V. 6 was very sensitive. Furthermore, both yellow and red included the infra-red, to which the cell is sensitive for some distance. Accordingly, a heat-absorbing screen was added, the combination being as shown in fig. 3. Furthermore, a deep blue screen and a dark red one, both supplied by Schott and Gen, were added to the four Corning glasses in use previously.

As already mentioned, in two of the later series the colour filters were placed beneath the opal glass.

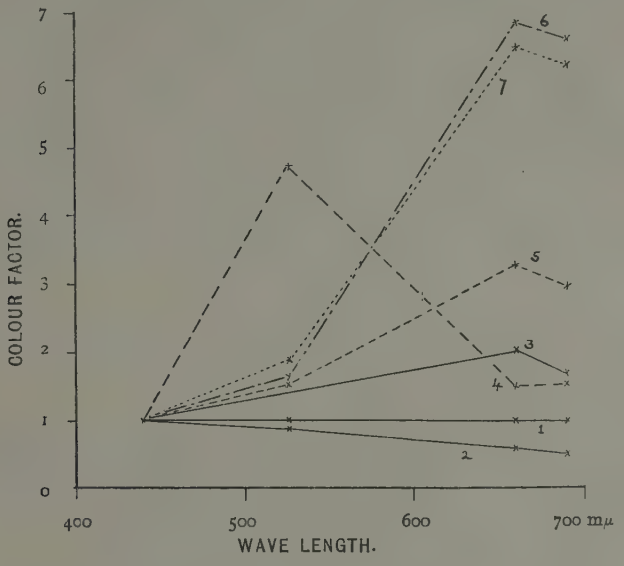

FIG. 5.

"Colour factors" of various types of light plotted against mean wave-lengths of the spectrum bands transmitted by various colour screens. (1) Light from a grey sky (taken as standard, *i.e.* "white"), (2) light from a blue sky, (3) pure sunlight, (4) light in deep shade under Taxus, (5) carbon arc, (6) gas-filled 12-v. lamp at 10·0 volts, (7) same at 12·0 volts. Determinations made with C.M.V. 6 cell and opal, but no heat-absorbing screen.

A convenient routine was developed for measuring the ratios, using the neon lamp method. The only drawback was that, under damp conditions, surface leaks prevented the use of a guard ring potential as high as 170 volts, which led to flashing with the photometer covered. Lesser voltages had to be

used and frequent checks made to ascertain the absence of "dark current" flashing, or its presence at a very slow rate of flash which could be allowed for.

The German deep blue could be used quite safely without the heat-absorbing screen, since it transmits no appreciable infra-red affecting C.M.V. 6. The same is true of the Corning green. Indeed, its combination with C.M.V. 6, which has a sensitivity minimum in the green, is already of relatively low sensitivity; this the heat-absorbing screen reduces still further. Accordingly, in deep shade a small leakage may be a serious matter, on account of which certain measurements on October 10 had to be rejected. Heat-absorbing glass of lighter tint and lesser thickness has been obtained for use, in the hope that it may avoid this trouble and give larger readings also in the red and dark red, without allowing an appreciable amount of infra-red to pass.

The neon lamp outfit may be standardized by direct comparison with a second photo-electric cell, the current through which is measured by a micro-ammeter or by our potentiometer apparatus (1925). This gives the illumination in metre candles. The rate of flashing is observed with a suitable condenser plugged in across the neon lamp, a convenient number of flashes being timed, and the rate per minute, which is directly proportional to the illumination, noted. By repeating this comparison with different condensers, and different intensities of illumination, the various ranges may be calibrated. It is important to remember that the capacity of the leads affects the rate of flashing, so that the apparatus should be standardized as nearly as possible under working conditions.

As a rule, in measuring the illumination in metre candles, some form of galvanometer or our potentiometer apparatus (1925) was used to measure the current.

The neon lamp method is, however, invaluable for comparing intensities using various colour screens. In this work the mean time of flash only need be determined. It is best to work with a series of observations, each covering short periods during which the photo-electric current is integrated. By this means slight variations in the intensity of the light, which may occur very irregularly, are reduced to little importance. In monochromatic photo-electric measurements such irregularities would affect the intensity, which is all that is being measured. But in heterochromatic work these intensity irregularities are interpreted as variations in the colour of the light, since they affect the ratio of, say, blue to red. Sometimes one obtains a very regular series; sometimes it is best to select for calculation a few observations which were obtained while the illumination had remained sensibly constant.

In former papers it has been mentioned that the passage of a white cloud vertically above the photometer had an appreciable effect in increasing the illumination, since the cloud reflected more blue light than the blue sky. Using the red-sensitive cell this effect became much more marked. For example, in a wood, the diffuse illumination on a clear day is largely that due to a number

of apertures admitting predominantly blue sky light. The white cloud, however, reflects light which has very approximately the colour composition of sunlight. When working with a red filter the effect is very remarkable, as there may have been no visual indication of any change, since one does not normally look at the zenith.

Another source of error has been the swaying of trees in the wind. It was rarely that the branches were motionless during our work, and at times their motion was so large in amplitude, and so irregular, as to make concordant observations hard to obtain.

As an example of the method of observation with the neon lamp, under rather favourable conditions, the following readings may be quoted. They were obtained between 2 and 2.30 p.m., G.M.T., in deep shade in a wood of *Picea excelsa* on September 3rd, the observations with different screens being made alternately:—

Blue.		Green.		Green/Blue.
10 flashes in 15·2 sec. 10 „ 14·6 „ 10 „ 14·2 „	40·9 f.p.m.	10 flashes in 25·8 sec. 10 „ 23·9 „	24·0 f.p.m.	0·59
Blue.		**Yellow.**		**Yellow/Blue.**
10 flashes in 14·3 sec. 10 „ 14·4 „	41·7 f.p.m.	20 flashes in 14·7 sec. 20 „ 14·6 „	81·9 f.p.m.	1·96
Blue.		**Red.**		**Red/Blue.**
10 flashes in 13·8 sec. 10 „ 14·0 „	43·1 f.p.m.	20 flashes in 15·0 sec. 20 „ 14·9 „	80·2 f.p.m.	1·86

The Colour Composition of the Light in Woods.

Data on the colour of light in woods or shaded sites have already been given in Table 6, in which, however, the blue is a little high, by reason of the infra-red transmission of the filter, and the yellow and red include some infra-red. It may be seen that in heavy shade, daylight factor 0·8–0·9 for blue light, the green is greatly increased, most of all under *Picea*; the yellow and red also show increases compared with white light.

In Table 7 results are presented which are free from the infra-red error, having been obtained with heat-absorbing filter in position. In this Table the diffuse light from a blue sky with white clouds at 10.30 a.m. on September 26 has been adopted as a standard.

TABLE 7.

Colour factors as found by C.M.V. 6 cell with opal and heat-absorbing glasses for Corning and other filters (over opal).* The daylight factor, which is given as a percentage, refers to blue light only. The daylight factor for any other colour is found by multiplying δ by the appropriate colour factor. (Colour factor for blue = Unity.)

Date.	G.M.T.	Place and Conditions. Year 1930.	δ	D. Blue.	Green.	Yellow.	Red.	D. Red.
Sep. 3	2.40 p.m.	Bickleigh, in wood, *Picea excelsa*, blue sky, clouds	0·8	—	6·15	2·40	5·13	9·1
Sep. 3	4.5 p.m.	Bickleigh, in open, sun clear ($\alpha = 26°$), white clouds	—	—	1·80	2·22	2·21	—
Sep. 3	4.25 p.m.	Do., sun through clouds ($\alpha = 24°$)	—	0·97	1·47	—	—	2·05
Sep. 19	11 a.m.	Plymouth, laboratory roof, sunlight screened,† sky mainly white, some blue	—	—	—	2·20	2·26†	—
		Do.	—	—	—	1·53	2·56†	—
„	1.30 p.m.	Do., full sunlight ($\alpha = 38°$), blue sky, light steady	—	—	1·20	2·38	2·05	—
		Do., sun screened, clouds over sun, variable	—	0·93	1·67	1·93	1·65†	2·04
Sep. 26	10.30 a.m.	Bickleigh, in shade of wall, sun and large white clouds, blue overhead	—	1·00	1·00	1·00	1·00	1·00
	11 a.m.	Do., sun ($\alpha = 36°$), not screened, open site	—	0·84	1·52	2·12	2·08	2·04
	12.30 p.m.	Do., bank at W. of *Quercus robur* wood, sky blue	—	1·02	0·90	0·85	0·82	0·84
	2.30 p.m.	Do., in oak wood, in shade	9	0·94	1·50	2·20	2·00	4·34
	3.15 p.m.	Do., in sun fleck ...	—	—	2·10	—	—	—
Sep. 30	1.30 p.m.	Shaugh, in wood of *Larix europaea*, in shade, blue sky, clouds.	14	1·08	1·66	1·81	1·97	2·39
	3 p.m.	Do., in shade of *Q. robur*	5	—	—	1·78	—	—
Oct. 10	11.15 a.m.	Antony, in wood in shade of *Q. ilex*, blue sky and clouds intermittently overhead	1·2	0·94	2·00	2·22	2·80	3·96
		Do. (Repeated)	1·2	—	1·92	2·68	—	3·67
		Do. (Repeated)	—	—	1·88	—	—	—
	12.30 p.m.	Do., in shade of *Q. robur* and *Q. ilex*	4	0·90	—	2·22	1·52	1·70
		Do. (Repeated)	4	—	—	—	—	1·43

* Or preferably under opal, as in the later determinations.

† On September 19th the screening wall was red brick, which may have raised the red values appreciably. Cloud reflections very variable.

By multiplying the values of δ for blue light by the colour factors for other colours we obtain the figures for the daylight factors given in Table 8.

TABLE 8.

The values of δ for various colours for the sites shown in Table 7.

Site.	Deep Blue.	Blue.	Green.	Yellow.	Red.	Dark Red.
Bickleigh, in wood of *Picea excelsa* ...	—	0·8	4·9	1·9	4·1	7·3
Bickleigh, in wood of *Quercus robur* ...	8·5	9·0	13·5	19·8	18·0	39·1
Shaugh, in wood of *Larix europaea* ...	15·1	14·0	23·2	25·4	27·6	33·5
Shaugh, do., but in shade of *Q. robur* ...	—	5·0	—	8·9	—	—
Antony, in wood of *Q. ilex*	1·1	1·2	2·4	2·7	3·4	4·7
Do., repeated, clouds intermittent ...	—	1·2	2·3	3·2	—	4·4
Do., but in shade of *Q. robur* and *Q. ilex* ...	3·6	4·0	—	8·9	6·1	6·8

Immediately after the determination of the colour of sky light had been made on September 26th, the colour of the full daylight was ascertained, followed by that of a pure blue sky with no white clouds. The extent of these changes and of those in woods may best be grasped by inspection of fig. 6.

In cases in which the reduction in the daylight factor is not very great, the colour of the light in the wood is increased somewhat in green, yellow, and red, but only to an extent to bring it rather nearer to a sky with sunlight than to light from a blue sky, dark red being somewhat exaggerated. With values of δ around one per cent. the influence of the light reflected from the leaves becomes of importance, and there may be marked increases in the green, red, and dark red. The amount transmitted through leaves is probably small. The region denoted as "yellow" still remains much as in a sky and sunlight mixture. The wave-lengths taken as the means for the screens are, Schott and Gen deep blue, 407 mμ, Corning blue 440, green 526, yellow 640, red 666, and Schott and Gen dark red 707 mμ. The "yellow," since it transmits red freely, has a mean transmission wave-length which is actually in the red. As regards the values of δ recorded, those in Table 6 were determined at the time in the usual way. The value of δ for September 3rd, 0·8 per cent., was obtained by measuring the illumination in the wood with a Burt cell and micro-ammeter, and that in the open by means of the Burt cell and the "thread recorder" already described (1930), which was set up on the roof of the laboratory in Plymouth some miles away. Since the sky was almost cloudless this was quite permissible.

The remaining values of δ in Table 7 are those found by Atkins and Stanbury (1930) for the same sites in September, 1929. The photometer was

set up as nearly as possible on the same spots. The general descriptions of the woods and the flora at the sites have been given in the paper just mentioned.

The work in the wood of *Picea excelsa* was carried out at a spot 9 metres in from the lower (west) edge of the wood close to the bole of a tree about 15 m. high; the ground around was devoid of all growth, but was quite moist, $\delta = 0{\cdot}8$ per cent.

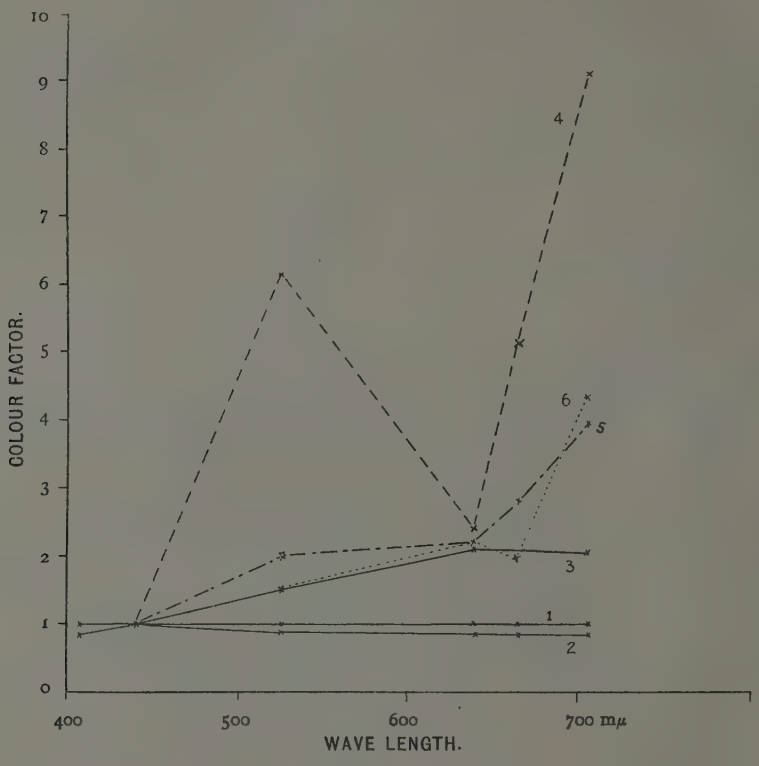

Fig. 6.

"Colour factors" of various types of daylight plotted as in fig. 5. (1) Light from a blue sky with some white clouds (taken as standard), (2) light from a very clear blue sky, (3) mixed sunlight and sky light, (4) deep shade under Picea, (5) deep shade under *Quercus ilex*, (6) moderate shade under *Q. robur*. Heat-absorbing screen used to cut out infra-red.

The colour measurements on September 26, in the wood of *Quercus robur*, were made at Site 3, Base A of September 6, 1929. Those under *Larix europaea* on September 30 were made at Site 3, Base A of September 9th, 1929, also near Site 4. On October 10 in the *Q. ilex* wood the position was that of Site 2, Base A, September 12th, 1929, and later near Site 6, Base B. Here the wood had been altered somewhat through the fall of a tree.

There can be little doubt that the remarkably large values shown in Table 7 and fig. 6 for deep red light are to be ascribed to the bright transmission of chlorophyll in the deep red.

The transmission band begins at about 690 to 700 mμ, and extends at least as far as the end of the visible spectrum. Its effect is so strong as to make a chlorophyll solution deep red by transmitted light if the layer of solution is more than a couple of centimetres thick; whereas for thinner layers the broad, but much less intense, transmission in the green renders the solution green. Thus, the deeper the shade the larger the colour factor should be for deep red.

Visual Observations of Light under Trees and Reflected from Leaves.

For comparison with the photo-electric measurements of colour we may record a few visual observations, made with a hand spectroscope, calibrated by means of the Fraunhofer lines and the mercury arc. These observations were made before the photo-electric measurements, to obtain an idea of the conditions.

Under a large *Taxus baccata,* with additional shade from saplings of *Sambucus nigra,* the daylight factor had been found to be 0·9 per cent. *Hedera helix* was dominant on the ground, forming a carpet. In the open the sun shone in a blue sky with clouds. Light reflected directly from the Hedera was very faint, with a maximum in the green at 552 mμ. Light reflected from an opal plate, glossy surface, placed horizontally on the Hedera, showed the red well, with an absorption band in the orange red; the green was bright, the blue less by far and cut off fairly sharply at about the G line, 431 mμ, though this may in part be due to the lesser sensitivity of the eye in this region.

The intensity of the blue light reflected from the shadow of the Sambucus on the ground opal was, as viewed through "minus red," No. 65A, and "minus green," No. 32, filters, very close to that of the mixed light transmitted by the 0·01 No. 96, "neutral tint," between it and the 1/8 plus 1/10 No. 96 screens, viz., 1/80, say about 1/90; the field of view was the area of the opal plate at the same distance in each case. On the high lights of the glossy leaves of Aucuba the blue showed up well, but in general the foliage, in shade from overhanging *Quercus ilex,* as seen through the blue combination, about matched 1/600 neutral tint, between 1/400 and 1/800. The blue combination darkens shadows. Apparently blue light is heavily absorbed by foliage. Both *Q. ilex* and Taxus reflect a large amount of red.

It is instructive to view the flora with blue, green, and red light obtained from combinations of the Wratten "minus blue," "minus green," and "minus red," Nos. 12, 32, 65A. The amount of red light reflected is somewhat surprising. With No. 65A, red flowers appear black, or disappear among the foliage; often, however, the anthocyanin blues in apparently red flowers show up strongly. In general the blue is absorbed heavily by leaves, save in those with very glossy surfaces.

The visual observations are thus in accordance with the photo-electric results.

Comparison of Sunlight and Sky Light.

In our work from 1925 to 1928 we used potassium cells for determining the ratio of the total vertical illumination to the vertical illumination due to diffuse sky light only; but from that onwards sodium cells were also used. It was necessary to study what difference might be introduced by this change.

Undoubtedly some of our earlier determinations made at sea under difficult conditions gave values for the ratio, β, which were too high, as it was hard to avoid shading rather too heavily. The values given in Table 9 were, however, determined on the roof, care being taken to cut off as little sky light as was possible when screening off the direct rays of the sun. In addition to the results obtained with a potassium cell, H, and the sodium cells, B 188 and B 223, those found with the thin film potassium cell K.M. 2 after prolonged standing, and with the red-sensitive C.M.V. 6, are also shown. The sodium cell was also tried, with a clear glass only, to get a result comparable to that with a non-diffusing ultra-violet transmitting glass, and with a Pyrex glass screen, which cuts out the shortest solar ultra-violet.

It may be seen that, for the ultra-violet (the screen has a maximum transmission at about 360 mμ), the value of β is distinctly lower than is that for the whole range of light to which the sodium cell is sensitive. In this, as in all other determinations of β using a filter of relatively low transmission, the uncertainty due to angle of incidence comes in; this has been discussed previously. With ultra-violet and Pyrex the loss of the shortest ultra-violet has raised the value of β slightly.

Between the values obtained with sodium and potassium cells there is no great difference. On the whole the sodium cells give lower values—those for June 21st, 11.12–11.49, for example. The high value for β at 12.31 has been allowed to stand, but nothing quite as high has since been obtained. Sometimes there is no significant difference between values for the two metals; thus on June 26th at 12.8, B 223 gave $\beta = 3{\cdot}52$; at 12.9, $\beta = 3{\cdot}44$ with H, and at 12.11, $\beta = 3{\cdot}47$ with B 223. One might expect, however, to find conditions under which the potassium cell values of β were appreciably greater than those for the sodium cell.

K.M. 2 having lost most of its red sensitivity, gave values only a little higher than a sodium cell, to which it became almost identical in behaviour with a blue filter.

C.M.V. 6 gave values of β about 1·5 times as great as the sodium cells. Values for daylight as measured by these types of cell have been shown in Table 3. It cannot be expected that the ratio will remain constant, as it must be increased by any cause that increases the proportion of red and yellow light. Thus, increased altitude of the sun, by raising the proportion of sunlight, should increase the ratio if the sun were shining, but would probably reduce it if the sun were obscured. With a blue filter C.M.V. 6 and B 188 gave almost identical values. The insertion of the Corning blue filter seems to raise the average wave-length of the light affecting the sodium cell, for β is increased somewhat.

TABLE 9.

Values of ratio of total vertical to vertical diffuse light (β) determined with various photo-electric cells and filters, on the flat roof of the Marine Biological Laboratory, Plymouth. The vertical illumination is shown in thousands of metre candles. Photo-electric cells; B 188 and B 223, sodium (Burt); H and K.M. 2, potassium; C.M.V. 6, thin-film caesium.

Date.	G.M.T.	Photo-meter.	Filter.	Conditions.	α.	V.	β.	
19/6/'29	11.10	B 223	Opal ...	Sun clear through high light haze,	59°	93·2	3·21	
	11.20	„	None ...	Blue sky, some light diffuse wispy	60°		2·67	
	11.22	„	Ultra-violet ...	clouds, wind S.	60°		2·41	
21/6/'29	11.12	H	Opal ...	Clear sun, blue sky, some clouds,	60°		3·51	
	11.13	B 223	„ ...	strong N.W. wind	60°	102·4	3·30	
	11.15	„	„ ...		60°		3·21	
	11.17	„	„ ...		60°		3·32	
	11.18	H	„ ...		60°		3·45	
	11.19	„	„ ...		60°	101·0	3·49	
	11.38	B 223	„ ...		62°	102·9	3·02	
	11.40	H	„ ...		62°	102·4	3·33	
	11.46	B 223	„ ...		62°		3·11	
	12.5	„	„ ...		63°	97·9	3·28	
	12.8	H	„ ...		63°		3·21	
	12.29	B 223	„ ...		63°	102·8	3·64	
	12.31	„	„ ...		63°	107·4	4·25	
	12.34	H	„ ...		63°	102·7	4·01	
	2.14	„	„ ...	High light haze	54°	85·1	2·86	
	2.27	B 223	„ ...		52°	87·9	3·11	
	2.32	K.M. 2	„ ...		51°		3·27	
	2.36	„	Opal + C. blue		51°		3·14	
26/6/'29	11.55	B 223	Opal ...	Sun clear, blue sky	62°	96·2	3·53	
	11.57	„	None ...		62°		2·68	
	11.59	„	Pyrex ...		63°		3·06	
	12.1	„	Ultra-violet ...		63°		2·18	
	12.3	„	Do. + pyrex ...		63°		2·34	
	12.7	„	Opal ...		63°	97·3	3·56	
	12.8	„	„ ...		63°		3·52	
	12.9	H	„ ...		63°		3·44	
	12.11	B 223	„ ...		63°	99·2	3·47	
18/9/'29	2.7	C.M.V. 6	„ ...	Sun clear, sky blue, some clouds	35°		3·48	
	„	B 188	„ ...		35°	54·1	2·29	
	„	B 188	„ ...		35°	53·7	2·33	*
	2.9	C.M.V. 6	„ ...		35°		3·43	
	2.10	C.M.V. 6	Opal + C. blue		35°		2·41	
	2.12	B 188	Opal ...		35°	54·1	2·43	
	2.14	B 188	Opal + C. blue		35°		2·62	
	3.0	C.M.V. 6	Opal ...		30°		3·31	
	3.2	B 188	„ ...		30°	42·7	2·20	†
	3.3	C.M.V. 6	„ ...		30°		3·34	

* $\frac{\beta \text{ with C.M.V.6}}{\beta \text{ with B. 188}} = 1{\cdot}49$. † Same ratio = 1·52.

Table 10 shows a number of successive observations of β made with C.M.V. 6 cell and various screens on two different dates. It illustrates the variations in this quantity that may be expected under different conditions.

TABLE 10.

Measurements of ratio of total vertical to diffuse vertical light (β) made with cell C.M.V. 6 with opal glass and with various filters (β_F) on roof of laboratory, Plymouth, September 18, 1929. The transmission of factors are for daylight at the time, determined with C.M.V. 6. At the end are three measurements made in Dublin on May 26, 1930.

G.M.T.	Conditions.	α	Filter.	Transmission factor.*	β	β_F	β'	β_F	β	Sun F / Sky F
10.35–10.50	Sun through light clouds, blue sky, white clouds up to 30° from horizon.	38	Red	35·9	2·15	2·86	2·30	2·80	2·13	1·86†
10.50–11.0		39	Yellow	36·3	2·04	2·95	2·29	3·21	2·31	2·21
11.0–11.12		40	Green	2·6	2·29	2·09	2·30	2·09	2·23	1·09
11.13–11.19	Do.	40	Blue	23·4	2·23	1·78	2·19	1·77	—	0·78
11.20	Do.	40	,,	—	—	—	—	1·84	—	0·84
11.22	Do.	40	,,	—	—	—	—	1·93	2·24	0·93
11.26–11.32	Do., clouds thickening	41	Heat abs.	15·1	—	2·02	2·14	1·98	—	1·02
11.33–11.37		41	,,	—	—	1·95	2·15	1·95	—	0·95
11.39–11.48	Sunlight decreasing	42	Didymium	44·4	—	1·98	1·71	1·80	1·82	0·98
11.49–11.55	Only faintest shadows	42	Tricolor red	36·1	1·24	1·23	1·16	—	—	0·23
11.56–12.1	Faint shadows ...	42	Minus green	54·7	1·38	1·44	1·31	—	—	0·44
2.15	Sun clear, sky blue, some clouds	35	Blue	—	3·43	2·41	—	—	—	1·41
2.20	Do.	35	Red	30·8	3·69	5·96	—	—	—	4·96
2.25	Do.	34	Yellow	35·8	3·70	5·96	—	—	—	4·96
2.34	Do.	33	Green	2·9	3 80	2·67	—	—	—	1·67
2.40	Do.	33	Tric. red	39·0	—	7·55	—	—	—	6·55
2.45	Do.	32	Minus green	54·5	3·49	4·26	—	—	—	3·26
12.20	Sun clear, blue sky ...	58	Blue	—	—	2·28	—	—	—	1·28
12.25	Do.	58	Yellow	—	—	6·4	—	—	—	5·4
12.30	Do.	58	Red	—	—	7·2	—	—	—	6·2

It will be seen that C.M.V. 6, with the four Corning filters under a clear sun (α = 35° to 33°) with blue sky and some clouds, at 2.12 to 2.34 p.m. on

* Transmission factor as determined at the time for skylight plus sunlight.

† The values are for the maximum given by sunlight under the conditions obtaining.

September 18th, 1930, on the roof of the laboratory at Plymouth, gave the following values for the ratio of vertical sunlight to vertical sky light (*i.e.* $\beta - 1$):—blue, 1·41; green, 1·67; yellow, 4·96; red, 4·96. Thus, if we take the diffused sky light on this occasion as standard, the colour factors for the pure sunlight work out as: green, 1·18; yellow, 3·52; red, 3·52; blue = unity by definition.

These figures may be compared with those given in Tables 6 and 10 for observations made in Dublin on May 26th, 1930, with $\alpha = 58°$. In Table 6 a grey sky on September 19th, 1929, was taken as a standard, so the factors for the sunlight are considerably smaller. If, however, we take the blue sky on May 26th as standard, the factors for sunlight become: yellow, 3·64; red, 4·00.

The greatly enhanced values for the sunlight/skylight ratio obtained towards the red end of the spectrum emphasise the importance of direct sunlight in all sites to which it gains access. It does not contribute much to the illumination in most deeply shaded sites, and is not considered in calculating their daylight factors, so that, if we take the latter as a measure of the total illumination during the day, we will seriously over-rate the relative average light in a wood by disregarding the effect of direct sunlight in the open. On the other hand our daylight factors have all been given for blue light, and the magnitude of the green and red colour factors for shaded sites given in Tables 6 and 7 shows how greatly the total daylight factor may exceed the blue daylight factor. These two effects tend to balance each other, and so it seems probable that the blue daylight factor, as found by a sodium or a potassium cell, is quite a useful index of the effective illumination at the given site.

In conclusion, we desire to acknowledge with thanks a payment from the Government Grant Committee of the Royal Society, which rendered possible the purchase of the photo-electric cells, etc. We are also indebted to the Royal Dublin Society and the Marine Biological Association of the United Kingdom for general laboratory facilities. Our thanks are also due to Miss F. A. Stanbury for much assistance in connection with field work, especially the neon lamp measurements, and to Mrs. Ingaborg Atkins for numerous galvanometer readings. Furthermore, the Director and Staff of the Wembley Research Laboratories of the General Electric Company gave us valuable advice, and kept us in touch with their latest work in the development of the photo-electric cells sensitive throughout the visible solar spectrum; for this we are very grateful.

SUMMARY.

1. Data are presented concerning the transmission of various colour filters, used in isolating different regions of the spectrum.

2. For the measurement of the photo-electric current with a cell sensitive throughout the spectrum, it was possible to use a micro-ammeter for light in the open. In shaded sites, however, it was necessary to use an Onwood portable galvanometer in a case with scale at one metre distance, or J. H. J. Poole's neon

lamp device. For field work the last named was found to be by far the most convenient.

3. The total weight of the outfit for measuring the colour of light in woodlands is 14 kg. with Onwood galvanometer or 17·4 kg. with neon lamp outfit.

4 For such work N. R. Campbell's thin-film potassium on oxidized copper photo-electric cell could be used, but on account of its stability the thin-film caesium vacuum cell, type C.M.V. 6 (Campbell), is to be preferred. The infra-red sensitivity of the cell may be suppressed by a Corning heat-absorbing filter to give a wave-length sensitivity curve approximately horizontal between 440 and 640 mμ. The behaviour of these cells was compared with that of Burt sodium cells and of a potassium cell previously used.

5. Using a type C.M.V. 6 cell and a diffusing opal glass, we may find the transmission factors of various colour filters. These factors depend also on the colour of the light source, and may be used (taking daylight of some definite type as a standard) in assigning values to the colours of daylight under other conditions or in woods, and of the light from artificial sources. The colour filter should preferably be placed beneath the diffusing plate, so as to eliminate the effects of variations in the obliquity of illumination.

6. The source of light in woods is predominantly that of the blue sky—or grey sky—rather than normal daylight with sunshine. Light in woods is, however, very poor in blue, relatively rich in green, is close to sunlight in its content of orange-red, and very much richer than either sky light, daylight, or sunlight in the deep red. This is probably due to the great transparency of chlorophyll for deep red. The smaller the daylight factor the more does the character of the light differ from that of the incident light, namely, sky light.

7. Some visual observations made for comparison with the photo-electric measurements showed that, in deep shade under *Taxus baccata,* light reflected from an opal plate placed horizontally gave a maximum in the green at 552 mμ with a strong absorption band in the orange-red, beyond which the red showed up well. The blue was of low intensity, and was cut off fairly sharply about the G line, 431 mμ.

8. Many measurements have been made of the relative intensities of direct sunlight and diffuse sky light. Sunlight being, relatively, much richer in the light towards the red end of the spectrum, the value of this ratio at any given time depends on the type of photo-electric cell used to measure it, and is greatly altered by the use of colour filters.

9. Values of the daylight factor in shaded sites have heretofore been given by us for blue light only. To obtain the value for any other colour, the value for blue must be multiplied by the appropriate colour factor. As blue light is very deficient in woods, the factors for other colours are generally much higher.

On the other hand, in comparing the average illumination in a wood with that in the open, we must not forget the effect of a direct sunlight, which is eliminated in finding the daylight factor. The latter gives, accordingly, too high an estimate for the average illumination in the wood. The blue daylight factor, being lower than the total daylight factor for white light, is possibly a better index of the relative average illumination at a shaded site, since to some extent it compensates for the over-estimation due to neglect of sunlight.

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No. 5.

OBSERVATIONS ON THE PHOTO-ELECTRIC MEASUREMENT OF THE RADIATION FROM MERCURY VAPOUR LAMPS AND FROM THE SUN, AND ON THE EFFECTS OF SUCH RADIATION UPON THE SKIN.

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Introduction.

This work arose from a request from the Medical Officer of Health, Plymouth, to examine the deterioration of mercury vapour arc lamps. A comparison of the effect of light from this source and from sunlight was naturally of interest in relation to our other work upon daylight.

It was shown in an earlier paper (1929) that the behaviour of the mercury vapour arc could, to some extent at least, be studied with an ordinary vacuum sodium photo-electric cell of the Burt type without amplifier, using 60 volts anode potential and reading the current on a micro-ammeter. This measures the total photo-electric current. The portion produced by radiation around 360 mμ may be ascertained by interposing a Corex red purple filter (Corning Glass Co.); an unpolished sheet 10·2 mm. thick was used. Again, the amount stopped by a Pyrex glass filter 4·0 mm. thick may be found, and when corrected for reflection losses and losses due to the visible light cut out by this filter, may be interpreted as a measure of the anti-rachitic potency of the radiation, since it has been shown by Luce (1926) that no anti-rachitic effect is produced by daylight passed through such a filter. It may be added that the glass used by Luce was 4·3 mm. of G 86 B, for which the makers now substitute Pyrex, which has practically the same transmission. G 86 B transmitted, as shown spectrographically, to 296 mμ, and, as shown spectrophotometrically, it had a 0·5 per cent. transmission between 300 and 305 mμ. In addition a filter of surface-flashed opalized glass was used.

Before discussing the method of comparing the relative proportions of the different regions of the spectrum of the arc, a few points of practical interest in the use of such lamps will be considered. As in the earlier work, the arcs studied were of the type sold as the Hewettic Levick Ulviarc Medical Lamp, air cooled, and were in use in the Plymouth Department of Public Health.

This lamp is designed to work at 230 volts, taking 3·5 amperes; but as the Plymouth voltage is only 210, the current is probably rather less. I am indebted to the Medical Officer of Health, Dr. A. T. Nankivell, D.P.H., and to Miss M. Smellie, M.B., D.P.H., for extending to me every facility in their use, and I am further indebted to Dr. Smellie for assistance in many of the measurements.

Photo-electric Examination of Mercury Vapour Arc.

It was previously shown that the arc, when started, rises at first, then falls, and almost at once again increases in activity very rapidly, attaining an approximately steady state at the end of 5 or 6 minutes from the start. It seemed desirable to ascertain to what extent this behaviour was modified when

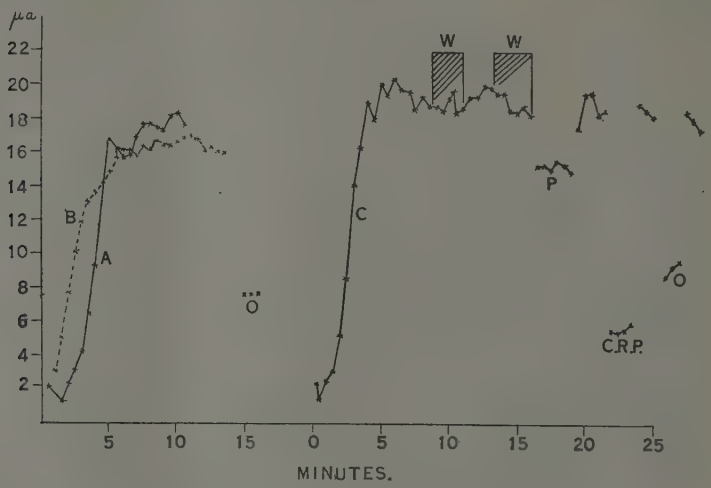

Fig. 1. Fig. 2.

The abscissae are minutes, the ordinates micro-amperes. The curves relate to the photo-electric current given by Burt vacuum sodium cells at 60 volts anode potential when exposed at a distance of 61 cm., with × 2 shunt in circuit, to mercury vapour arc lamp No. 2—the oldest.

Fig. 1.—April 29, 1930, A, lamp started cold, B, lamp started warm.

Fig. 2.—July 22, 1930, curve C. Effect of air current at cross hatching W. The curves O, P, C.R.P. relate to the filters.

the lamp was already hot from previous use, for if the initial period were much shortened owing to the previous heating, it might prove an economy to switch off the light between the exposure of successive patients. Fig. 1 shows the behaviour of lamp No. 2—when started cold, A, and when re-started after a five minute interval, B. It may be seen that in the latter there is no initial

drop, and a large percentage of the final illumination is reached a minute earlier; none the less the maximum is not reached any sooner. The lamp was run again for 11 minutes, with the Corex red purple ultra-violet filter in position; the mean reading from 7–11 minutes was 10·17 μa. The current was then switched off from the lamp for one minute only. When re-started, since the lamp was still warm, the first reading was 6·7 μa; 8·20 μa was reached at the end of one minute and 9·82 after 3 minutes. The mean of 7–11 minutes was 9·87 μa. Allowing for the variations met with in the lamp, it may be said that the previous maximum was reached again. It may also be concluded that, had the lamp been overheated from a long run, a cooling period of one minute would have lowered its temperature and that of its surroundings so greatly that on switching on again the original maximum would have been recovered; this, no doubt, would in time fall slowly as the overheating again developed. The cooling period of five or ten minutes originally given may therefore be reduced to one minute.

The Burt cell, which in shape is similar to an electric light bulb, pear type, and has a large area free from deposit (the window) on one side, was exposed so that the perpendicular from the middle of the surface of the tubular lamp to the bulb of the cell was 61 cm. (2 ft.), and was normal to the plane of the window of the bulb. This distance was taken as being that at which patients are exposed in Plymouth.

It was suspected that the irregularity of the curves obtained in earlier work and in Fig. 1, curve A, was due to the effects of air currents cooling the tube, as it seemed unlikely that the current varied to such an extent. The A curve was obtained while a large window was open; during the B measurements the window was shut, and the air in the room must have been free from any strong currents. The curve obtained was rather more regular. The portion marked O was obtained with opalized glass interposed.

The same lamp* was used three months later, curve C, Fig. 2, with window closed. A strong air current was made on two occasions, at the times indicated by the cross hatching marked W, by means of a towel. The portions of the curve marked P, C.R.P., and O were obtained with interposition of Pyrex, Corex red purple, and opalized glass. The effect of the breeze was to reduce the mean current to 97·1 and 96·8 per cent. of that without such cooling. With no breeze the fluctuation in current, minimum divided by maximum, was 94·9 and 93·5 per cent., with breeze 96·8 and 94·1 per cent. So the current is no steadier. One must conclude that the irregularities are in the main due to variations in the supply voltage. The responses of the cell were reduced to 47·6 per cent. (Fig. 1) and 51·8 per cent. (Fig. 2) under opal; 82·2 per cent. under Pyrex, and 30·3 per cent. under Corex red purple, the thicknesses being as before.

* The position of the reflector had been altered.

Figs. 3 and 4 show the behaviour of No. 3 lamp on the same two dates, April 29 and July 22, 1930. In Fig. 3, O′, the opal had been adjusted to be more accurately perpendicular than in O. The transmissions were:—O, 56·6, O′, 61·0 per cent., and 55·5 per cent. in Fig. 4; with Pyrex 80·2 per cent. as a mean of nine readings against seven unscreened, and Corex red purple 29·6 per cent.

The lower curve in Fig. 4 shows the behaviour of No. 3 lamp through Corex red purple on July 30; the dotted line connects with the curve obtained

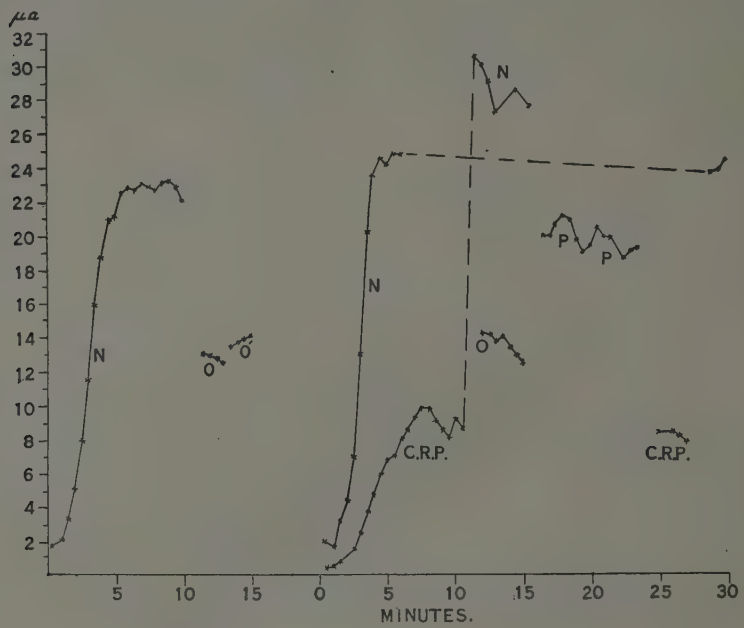

Fig. 3. Fig. 4.

Abscissae and ordinates as before. The curves relate to lamp No. 3 on April 29 and July 22 respectively. The portions marked N have no filter in position. The lower curve in Fig. 4 was obtained with Corex red purple filter in position on July 30.

when the screen had been removed. N in this figure and the next denotes no screen. The Corex mean values indicate a transmission percentage 29·4. The ultra-violet portion of the radiation does not attain its maximum till about a minute or two later than the total radiation, namely, seven as against five to six minutes.

Fig. 5 shows the behaviour of No. 4 lamp, which had never been used save in the tests necessary during manufacture and installation. The gaps in the curve P1, P2, P3 denote the times at which the Pyrex transmission percentages were determined to be 76·6, 76·3, and 74·1 respectively. The C1 and C2 gaps

relate similarly to the Corex, and gave 34·0 and 34·4 per cent. The lower curve is for Corex alone, obtained after a ten minute interval for cooling, the lamp having done the 43 minute run as shown. The Corex transmission percentage here is 33·6.

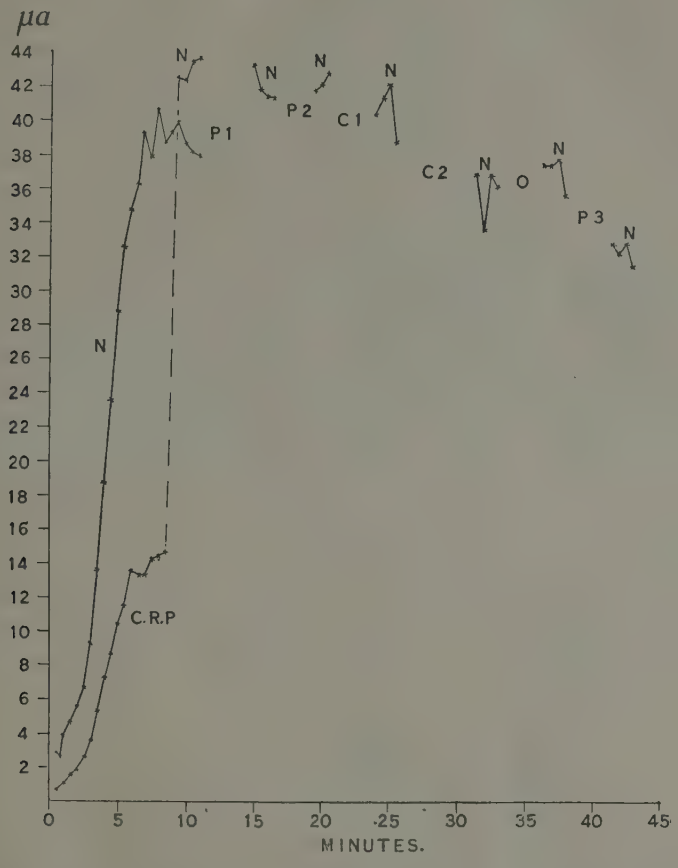

FIG. 5.

Abscissae and ordinates as before, also lettering. The curves show the behaviour of No. 4 lamp, unused as yet in the clinic; the lettered gaps are where the filter ratios were determined. The lower curve was obtained, after the lamp had cooled for 10 minutes, with Corex red purple filter in position.

During the long run the lamp behaved somewhat irregularly, due apparently to irregular supply, but it undoubtedly fell off as the temperature rose to too great an extent, the final value being close to three-fourths of the maximum. A similar run, of 47 minutes, with lamp No. 3, which had had about 190 hours use, gave a falling off of about 16 per cent. After the ten minutes cooling of

No. 4 lamp, the initial maximum was again reached in the second run. Possibly cooling by means of a breeze might, towards the end of the long run, have raised the output of the lamp as regards the radiation measured, instead of lowering it as shown in Fig. 2. Unlike a black body, the output of short wave radiation is reduced when the temperature exceeds a certain value. This has long been known, but the exact relation has recently been determined by Asada (1931).

It seemed possible that the falling off in the readings obtained during long runs of the lamp might in reality be due to fatigue of the photo-electric cell. This was tested during the 47 minute run of No. 3 lamp, by covering the cell for periods of one half, one, and five minutes. In no case was there any sign of fatigue, for the readings after covering were lower than before covering, as one would expect owing to the longer duration of the run.

The value of a stainless steel reflector was questioned by Harris (1929). He found that a more intense radiation was maintained without a reflector, since the lamp did not become overheated to the same extent, viz., the 25 per cent. loss shown in Fig. 3 did not occur. Stainless steel is a good reflector for heat, but only reflects 45 per cent. of radiation at 320 mμ, incident normally (Luckiesh, 1929), and for shorter wave-lengths the reflection would be less. The lamps we examined had, however, highly polished reflectors of aluminium, which metal reflects up to 68 per cent. at 320 mμ. The value or otherwise of the reflector could not be tested by removing it, since it was not detachable, but the effect of placing a black cloth between the reflector and the lamp was tried. In doing this the reflector was screwed back as far as was possible. In this position the radiation received by a photo-electric cell at 61 cm. is reduced to four-fifths of the amount received when the reflector is screwed forward nearly as far as it will come; the precise end position is immaterial. It was found that for the total radiation as measured by unscreened sodium cell, the values obtained were as follows:—

$$\frac{\text{No cloth, reflector back}}{\text{Black cloth in position}} = 2{\cdot}12.$$

$$\frac{\text{No cloth, reflector forward}}{\text{Black cloth in position}} = 2{\cdot}71$$

With the Corex red purple filter, passing ultra-violet light, the ratio 2·71 is reduced to 2·04. It is accordingly clear that a reduction of 25 per cent.—or even more—due to overheating does not outweigh the advantage of having a reflector, save that without a reflector it would be possible to treat two patients simultaneously, giving longer exposures. This might in some cases be desirable.

If we compare the total radiation from the three lamps in July, 1930, by means of the micro-ammeter readings, we find No. 2, No. 3, and No. 4 giving 17, 24, and 42 μa respectively, or 40, 57, and 100 per cent. Multiplying the total current for each by the corresponding values obtained under Corex red purple, namely, 0·303, 0·295, and 0·342, we obtain 36, 49, and 100 as the relative efficiencies for this ultra-violet range.

For Pyrex we have to proceed somewhat differently. The new lamp gives, through Pyrex, a percentage transmission of 75·7, namely, 24·3 per cent. has been stopped. Of this loss we find 8·3 per cent. was a loss due to stoppage of the visible and the longer ultra-violet, for such a value was found for the Pyrex loss when this filter was placed over opalized glass, which stops short ultra-violet and much of the longer also. Accordingly only 16 out of the 24·3 can be attributed to the effect of the loss of short wave radiation, able to penetrate the thin soda glass bulb of the photo-electric cell, but stopped by the Pyrex, 4 mm. thick. Similarly we obtain for the No. 3 lamp 11·5 and for the No. 2, 9·5. These values may be expressed as ratios with respect to the light response other than that due to the Pyrex-stopped radiation, viz.,

$$\frac{16}{84} = 0{\cdot}19, \qquad \frac{11{\cdot}5}{88{\cdot}5} = 0{\cdot}13, \qquad \frac{9{\cdot}5}{90{\cdot}5} = 0{\cdot}105.$$

Dividing by the value for No. 4 we get for Nos. 3 and 2 respectively 68 and 58 per cent. This shows how greatly the radiation in the older lamps has deteriorated with respect to the proportion of valuable (anti-rachitic) and other radiation measured by the cell used.

To assess the total radiation as anti-rachitic, it is necessary to multiply in each case by the factors 16, 11·5, and 9·5 per cent. respectively, giving 6·72, 2·76, and 1·62 micro-amperes or 100, 41, and 24 per cent. The foregoing results may be tabulated as follows:—

TABLE.

Proportions of total, ultra-violet, and anti-rachitic ultra-violet radiation in mercury vapour lamps of different ages; the number of hours' use is only an approximation.

Lamp.	Hours of use.	No screen.	Corex red purple.	Anti-rachitic stopped by Pyrex.
4	0	100	100	100
3	190	57	49	41
2	750	40	36	24

Certain of the earlier measurements on these lamps, during 1929, were made with photometer at 50 cm., instead of at 61 cm. To convert according to the inverse square law the factor 0·67 must be used. On account of the reflector, however, and the shape of the lamp, a direct determination seemed desirable, and gave the ratio 0·82. The results obtained were irregular, no decrease with time being apparent in some cases. It was then ascertained that the practice of the operators had been to compensate for such decrease by screwing down the reflector into its position of greater efficiency. Accordingly measurements of the radiation have little value unless accompanied by a statement as to the position of the reflector at the time.

It should be added that sometimes the "on/off" ratio for a screen has been spoken of as the percentage response rather than the transmission. This has been done because the wave-length sensitivity curve for sodium has a maximum at about 360mμ, so the Corex red purple filter, for example, which transmits freely in this region, would appear to transmit far more than in reality it does, so far as the total radiation is concerned. In addition, in the case of the opal, the transmission, though approximately non-selective in the visible, is selective in the ultra-violet, and, further, alterations in the angle of incidence are introduced.

As regards the deterioration of individual lamps, the work of Gillam and Morton (1927) and our previous paper (1929) may be consulted. Lamps Nos. 2 and 3 have since been in use over a year; the values given for hours of use is an approximation based on the work of the clinic. At the end of July, 1930, No. 2 was considered too low in efficiency to be economical for further use, not because it would not produce erythema, but because too long an exposure was required, and the treatment of numerous cases became too tedious.

The Integration of the Photo-electric Current by the Neon Lamp Method.

In 1928 a method was described by J. H. J. Poole whereby a photo-electric current could be integrated over any convenient period of time by counting the flashes of a neon lamp connected across the terminals of a condenser. By means of an amplifier each flash may be heard as a rap on a loud-speaking telephone, which is useful for demonstration purposes. This was used by J. H. J. and H. H. Poole (1930), in a slightly modified form, to measure illumination in a lake. The advantage of the method, with a variable current, lies in the fact that it is a measure of the mean current over the time chosen. It appeared quite suitable for use with the mercury arc. A series of condensers, 0·5, 0·05, 0·005, and 0·0005 micro-farad, are fixed in the apparatus as used for the lake work, the lowest capacity being used for low illumination. With the sodium photo-electric cell (B 224)* and the Corex red purple ultra-violet transmitting filter in position, it was found advisable to use the 0·5 μF condenser with the mercury arc. The initial rate of flashing was 3·04 per minute, and after six minutes a nearly uniform rate, 29·7 flashes per minute, was reached; as before, the photometer was at 61 cms. from the lamp. The results are shown in Fig. 6, from which it may be seen that the curve is of greater regularity than are the corresponding curves for single observations in Figs. 1–5. The instrument is of low cost and easy to use. It is necessary, however, to have a total voltage of at least 210, since the neon lamp requires about 130 to 150 volts to induce flashing, and the potential difference across the photo-electric cell should be at least 60 volts. The voltage actually used was 252, with 150 volts on the guard ring. Under these conditions there was no flashing with photometer darkened and 0·5 μF capacity,

* Used for mercury arc work previously.

though with a lesser capacity, 0·005 μF, there was a slow rate of flash, indicating a slight leak, which was too small to be appreciable with the larger condenser used in the measurements. It may be seen that the steady maximum was reached in six minutes, as before, for the ultra-violet light.

A somewhat similar arrangement was used by Rentschler (1930) for integrating the photo-electric current from a uranium cell, sensitive below 320 mμ. The neon lamp he used had two anodes, one of which was connected to a high tension battery, the flash from the other one resulting in a trigger action, so that a mechanical relay counter was operated or a graphic record obtained. In bright sunlight Rentschler's apparatus gave 100 flashes in five minutes.

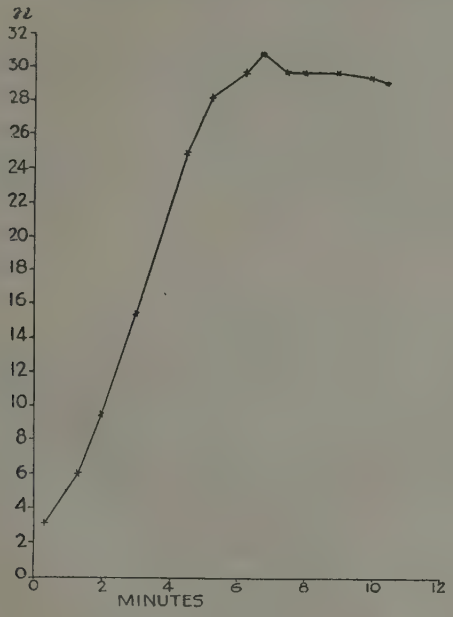

FIG. 6.

The abscissae are minutes, the ordinates give the numbers of flashes per minute of a neon lamp, used to measure the photo-electric current from a sodium cell (B 224, under an ultra-violet transmitting filter), according to the method of J. H. J. Poole. The source was No. 4 mercury vapour arc, at a distance of 61 cm.

Observations on the Production of Erythema by means of Mercury Vapour Arc or Daylight.

The correlation of the amount of irradiation and the physiological effect is not easy. The latter is usually measured by noting the time required to produce erythema, which is known to vary greatly from one individual to another. Moreover, on any given area it does not begin uniformly. Furthermore, the latent period, between irradiation and the appearance of erythema,

varies with the wave-length of the radiation in an inverse manner. Thus, after insolation, erythema may be pronounced at once with an over-dose, or almost at once with lesser dose; with a mercury vapour arc the symptoms appear in two to three hours, according to the exposure; whereas in the case of X-rays a harmful effect may not begin to be apparent till a week or ten days after exposure, even with very severe burns. With a burn from infra-red radiation, on the other hand, the effect is almost instantaneous. We have heard it stated most emphatically that the production of erythema (from sources other than heat burns) always has a considerable latent period, and that, when exposure to the sun appears to produce an almost immediate effect, this is due to the heat. An experiment to be quoted later shows that this is not so, for exposures under lantern plate glass up to two hours in full sunshine gave no erythema, whereas much shorter exposures under quartz or vitaglass gave intense erythema. On another occasion it was stated that vitaglass did not transmit therapeutic ultra-violet light, since a prolonged exposure of bacteria under it to radiation from a laboratory source (a flame carbon arc apparently) did not prove lethal. The listener was at the time painfully aware of the effects of exposure to sunlight through this glass, but there was no opportunity for reply.

It seems to be assumed that the production of erythema is governed by the formula

$$\text{Intensity} \times \text{time} = k.$$

This does not hold exactly for a photographic plate, and may not do so for erythema production. What seems to be aimed at usually is irradiation with an artificial source sufficient to produce a slight degree of erythema or to fall just short of this, not enough to produce deep pigmentation, which would necessitate longer exposures. Rollier, however, appears to aim at the production of a general pigmentation through graduated exposure to sun and sky light, which certainly gives what one may term a more healthy appearance. In this connection reference may be made to the work of Hill (1927) and of Tonney, Somers, and Marti (1928).

When new, a mercury vapour arc at 61 cm. distance may produce a slight erythema in one minute and a very definite erythema in two minutes. After being in use for a couple of hundred hours it may still give erythema in two minutes, though not quite as intense, and appearing in nearer three than two hours after exposure. When first switched on, an exposure up to $4\frac{1}{2}$ minutes may fail to give anything more than very slight erythema, which is in keeping with the current as shown in the figures.

Sunlight in Plymouth, on the sea front, on August 14, 1928, gave erythema for 30 minutes, and more intensely for 45 minutes exposure, but none at all for 15. The exposures were between 1.30 and 2.15 G.M.T., and the erythema did not develop for some hours in a subject with fair skin.

On July 18, 1928, two subjects were exposed, one with dark hair and skin that readily pigmented, the other with skin tending to peel without much pigmentation. The abdomen of each was exposed between 10.45 and 12.45 G.M.T.,

and photo-electric measurements of the light were made every two minutes throughout with a potassium vacuum cell, which had been standardized against an open carbon arc (Poole and Atkins, 1928). The mean values for the illumination for half hour periods were 107·0, 111·5, 114·4, and 115·8 thousand metre candles, mean 112·1. The ratio, β, of the total light falling on a horizontal surface, to the diffuse light when the direct sunlight was screened off, was 3·8 immediately before and 4·6 immediately after the exposures. This shows that the day was an exceptionally clear one, since the diffuse light is low, whereas the total illumination was high, 112 thousand metre candles. What was received by the subjects was perhaps five per cent. less, since they were on the flat roof, the cell on the low parapet. The dark subject had exposures of $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, and 2 hours, the half hour being the last. Well-marked erythema developed in each arena.

The light-skinned subject received irradiation for $1\frac{3}{4}$, $\frac{1}{2}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, 2, 1, and $\frac{1}{2}$ hours from left to right, starting with the first half hour exposure and ending with the last half hour exposure. In every case the exposure must have been well in excess of the erythema dose, for a marked effect was visible immediately after the end of the exposures. Other areas of the abdomen and chest were covered with lantern plate glass (film removed), vitaglass, and cathedral vitaglass, fused transparent silica, and milky fused silica—a crucible lid. The thicknesses and approximate transmission limits were as given in the next section. Under the lantern plate glass there was absolutely no effect to be seen, under the milky silica there was a slight erythema. Under the other three the erythema was painful. The marks of these exposures, especially the time series, remained for several months, not as pigmentation, which was slight, but as capillary dilatation, for on pressing slightly over these areas the skin blanched and no pigmentation could be seen. There was, of course, extensive peeling.

We see that here an exposure to the ultra-violet accompanying 107 thousand metre candles visible radiation for half an hour was more than enough to produce erythema, namely, less than 53 thousand metre candle hours was required. Had the illumination, however, been 53 thousand metre candles, it is unlikely that one hour's exposure would have produced erythema, since the intensity of the active portion of the ultra-violet would probably have been reduced by considerably more than half.

Similar erythema tests were carried out on June 19, 1929, exposing the inner side of the forearm. The sun was clear through high light haze, sky blue, with some diffuse wispy clouds, wind S.—from the sea, and light. Readings were made with a sodium photo-electric cell beneath the Corex red purple filter. Averaged over five minute periods, these gave between 11.30 and 12.10 G.M.T. the following readings: 20·0, 19·5, 18·5, 18·7, 19·2, 19·2, 19·5, 19·5, mean 19·3; this showed that the light was fairly steady. Exposures were given of from 10 to 40 minutes, increasing by 5 minutes at each step, making seven in all; the whole arm was exposed at the start, at the end only one strip remained exposed. Immediately after the exposures had ended, there was no sign of erythema, but twenty-five minutes later the 40 minute exposure showed marked

erythema and the 35 minute showed slight erythema. After 75 minutes from the end, the 35 minute exposure showed a well-marked and the 30 minute a slight erythema; furthermore, the four remaining exposures were all slightly mottled. At the end of 150 minutes after exposure the well-marked erythema had extended to 30 minute strip, the 25 and 20 having slight erythema. The 35 minute was perhaps rather more marked than the 30, but the greatest difference was undoubtedly between the 30 and 25 minute strips. About 24 hours later the reactions showed little further change. From these observations it may be appreciated how difficult it is to fix precisely what is the time required to produce erythema, even 10 minutes has some effect, whereas 30 minutes is probably the most sharply defined exposure, and should be taken as the time for erythema production in this case.

The illumination at 11.0 and 12.18 G.M.T. was in each case 93·2 thousand metre candles, so 46·6 thousand metre candle hours, or rather its far ultra-violet component, just sufficed to produce erythema. The anti-rachitic component we are unable to compare directly with the total, as was done for the mercury vapour arc; in the latter the incidence was always normal, whereas in the open the angular distribution varies, and with it the thickness of the light filter, which is interposed, varies also. It was, however, found, immediately after the exposures had ended, that the red purple Corex glass transmitted 13·2 per cent. of the total for unscreened cell, or rather that the cell gave a 13·2 per cent. response under this filter. At 11.25 the value $\beta = 2{\cdot}4$ was found for the Corex filter. Pyrex gives a response percentage of 91·7 for light passing opalized glass, 84 per cent. for unscreened cell reading, and 70 per cent. for light passing Corex filter. Correcting for the visible light it stops, we find that 78·3 per cent. of the Corex ultra-violet is Pyrex-passing, which leaves 21·7 per cent. as the amount having physiological action in producing erythema; with respect to the unscreened cell the amount is 21·7 per cent. of 13·2 per cent., viz., 2·9 per cent. The figure for Pyrex alone was shown as 84 per cent., which becomes 91·5 per cent. when corrected for the loss of visible light (viz., 100/91·7 of 84 per cent.). One is therefore left with a choice of using the Corex filter reading, or the difference between the unscreened and the Pyrex reading, as a measure of the physiologically active ultra-violet. But as already explained, neither is exact. For example, on June 20, 1929, which was entirely overcast at 10.20 G.M.T., the Corex filter gave a response percentage of 13·0, as against 13·2 at 12.20 on 19th, 14·3 at 2.15, and 13·8 at 2.30. Yet the 19th was a sunny day, effective in producing erythema, whereas on the 20th the grey sky had no such effect.

One is, therefore, compelled to make use of some method of diffusing the light so that the ultra-violet also may be diffused, and so may always have the same angular distribution. The surface flashed opalized glass we use stops all short ultra-violet. Dorno (1922) uses with his cadmium cell a matt "uviol" glass, but for direct sunlight only. This necessitates measurement with a sensitive galvanometer, whereas we are seeking to develop an outfit containing only sturdy portable instruments. The suggestion previously made (1930), to

use a diffusing sphere coated with magnesium carbonate internally, may serve, but has not been tried as yet. In this, light is admitted through a window in the top of the sphere, whereas the window for the cell is at right angles to this. To keep out rain the upper window might have a quartz covering.

The erythema-producing radiation of sunlight may, however, be more intense, relatively to the mercury arc, than the comparisons made here would lead one to believe, for Shattock and Waller (1929) have shown that erythema production can be modified by irradiation with infra-red or by heating by conduction. Heating after ultra-violet irradiation, or along with it, diminishes or suppresses and delays erythema; heating before irradiation increases erythema, the time of appearance not being influenced appreciably. Since there is far greater heating during exposure to full sunlight, than to the mercury arc, it seems clear that the erythema production due to sunlight must be relatively reduced.

Visual Observations on Ultra-violet Transmission, using Beck's Ultra-violet Spectroscope.

This instrument gives qualitative results, which, however, may be quite useful. There is a graduated scale beside a spectrum produced by fluorescence. A certain amount of parallax may occur in using this scale, but this can be allowed for and the correct position for the eye ascertained by checking against the mercury vapour arc. Thus the strong line at 313 mμ appeared as a bright fluorescence at 310–300 mμ, mean 305 mμ, necessitating a correction of 8 mμ. The figures given here have not been corrected by this amount, as it may be an over-correction in many cases. There may, however, be this amount of uncertainty it seems.

An arc which had been in use at the clinic, for four months only, appeared fairly bright in the bands down to 230 mμ and faintly to 210 mμ.

A sheet of fused quartz, 2·3 mm., interposed reduced the brightness considerably, and transmission appeared to cease at 230 mμ. It had not been specially cleaned, so it appears that a very careful cleaning is necessary to obtain the good transmission which quartz can give. All screens tested were wiped carefully with soft washed cotton fabric.

Corning Corex ultra-violet transmitting clear glass, 8·4 mm., a special calcium phosphate mixture—transmitted well down to 255 mμ.

Clear "Vitaglass," 2·7 mm. thick, transmitted well to 298, moderately to 295 mμ, and faintly a little beyond.

"Cathedral vitaglass," which has an uneven surface, was very faint beyond 300 mμ, thickness 4·2 mm.

"Holviglass," 3·0 mm., and "Sunrayglass," 1·8 mm., appeared to be about the same as "Vitaglass."

Pyrex, 4·3 mm., transmitted to 315, where it was sharply cut off.

Corex red purple, 10·2 mm., transmits feebly in the far red, and again in mercury vapour arc light from about 360 mμ to 280 mμ. It really extends further towards the visible, but the strong mercury line at 366 mμ is not

succeeded by another till 405 mμ in the visible. In this region, 360–280 mμ, the parallax error evidently came in. The red transmission of this filter does not matter when it is used with a sodium cell, but with a red-sensitive cell it has to be combined with a Corning light blue-green ultra-violet transmitting filter, G 584 J, 4·6 mm., to cut out the red.

Glass of ordinary spectacles, slightly blue tinted, 2·1 mm., transmits to 313 mμ, while spectacles of Crookes glass, 2·1 mm., cut off at 400 mμ. Cheap "smoked" glasses (price, one shilling or one and sixpence) were found to transmit to 360 mμ, while the special glasses used in the clinic by those engaged in treating patients transmitted no ultra-violet at all. In both the visible transmission was low.

Ordinary plate glass, such as used in a lantern slide, 1·7 mm., transmits to 370 mμ. Observations may also be made with this fluorescent spectroscope pointed at the sun. The ultra-violet from the sky alone is too weak to cause any fluorescence even with slit at its widest. As is well known, the erythema-producing effect of sunlight is not powerful late in September, so it seemed of interest to observe how far such visual observations could detect the ultra-violet. On September 20, 1928, the sun rose through light low clouds, with blue sky and a very light N.E. wind. At 7.20 G.M.T. no transmission beyond 390 mμ could be observed, and at 7.45 there was weak transmission a little beyond 385 mμ. At 8.10 there was a moderately strong effect down to 320 mμ, and at 8.25 there was some fluorescence down to 305 mμ. At this time the Breakwater three miles away was not very clear owing to smoke haze. By 9.30, however, the Eddystone lighthouse, 12 miles away, was exceptionally clear. The sun was free from all cloud, save a suspicion of high haze. The effect was fairly distinct to 305 and faint to 295 mμ.

Again on November 5, 1928, at 9.45 G.M.T., 390 mμ radiation was clearly seen and faintly on to 330 mμ. At 12.45 it was well marked to 380 and rather more distinctly than before down to 320 mμ. There was a blue sky, with sun through a light east wind cloud haze. On November 14 there was a clear sun about noon, with blue sky and white clouds, wind S.W., namely, from the sea. The effect was strong to 310 and faint to about 305 mμ.

It may be concluded that this spectroscope is quite a useful guide as to whether the sunlight contains an appreciable amount of anti-rachitic or erythema-producing radiation.

Photo-electric Measurements of the Ratio of Total to Diffuse Ultra-violet Radiation.

For the reasons given previously regarding the effect of alterations in angular distribution of light upon the amount transmitted by filters, it is impossible to get accurate measurements of the ratio, β, unless some diffusion method be adopted. Roughly comparative measurements may yet be made and are instructive. It has been shown elsewhere (1931) that for red light β may be as high as 6, whereas for blue light it rarely exceeds 3·5 as determined with sodium cell under diffusing opalized glass.

The following observations were made:—On June 19, 1929, at 11.0 G.M.T., with opal screen, $\beta = 3{\cdot}21$; at 11.20, opal off, $\beta = 2{\cdot}67$. Here the combined effect of altering the angular distribution and admitting ultra-violet, previously cut out, has lowered β. At 11.25, with Corex red purple filter, $\beta = 2{\cdot}41$, showing conclusively that the diffuse light is relatively richer in ultra-violet than the total light, up to the blue, to which the sodium cell is sensitive; at 12.13 the Corex filter gave $\beta = 2.30$.

Again on June 21, 1929, between 11.30 and 11.38 G.M.T. there was a clear sun, blue sky, some clouds, strong N.W. wind; vertical illumination 103 thousand metre candles. With no filter $\beta = 2{\cdot}58$, with Pyrex filter $\beta = 2{\cdot}54$, with Corex red purple filter $\beta = 2{\cdot}18$. Corex and Pyrex together one would have expected to have given a smaller value, but $\beta = 2{\cdot}34$ was found. With opal filter $\beta = 3{\cdot}02$. It is clear that the sunlight and skylight here exert about equal effects upon the cell, when ultra-violet light only is considered, whereas with the addition of blue light the ratio becomes about one sky to one and a half sun. From the opal filter value we see, however, that the latter should be one to two, namely, the sunlight should be multiplied by a factor 1·33. It seems, therefore, legitimate to conclude that instead of the sunlight and skylight having an equal amount of ultra-violet around 360 mμ (Corex maximum), the ratio should be raised to 1·33, viz., $\beta = 1{\cdot}18 \times 1{\cdot}33 + 1{\cdot}00 = 2{\cdot}57$. Such June values, of course, show the sun exerting its maximum effect; its value at lesser altitude would be smaller.

Again at 2.20 G.M.T. the same day the sun shone through high white haze, sky blue in east, white in west, wind S. Observations at 2.10, 2.20, and 2.25 gave $\beta = 1{\cdot}74$ with opal, and V = 73 thousand m.c., with Corex $\beta = 1{\cdot}75$, and with Corex + Pyrex $\beta = 1{\cdot}74$. Here the angular distribution effects and the variations in ultra-violet must just have cancelled out.

In conclusion the author desires to acknowledge his indebtedness to the Government Grant Committee of the Royal Society for defraying the cost of photo-electric cells; to the Marine Biological Association, Plymouth, for various laboratory facilities; to the Royal Dublin Society for facilities for standardizing cells; and to Drs. J. H. J. and H. H. Poole for kindly lending him their neon lamp apparatus used in the study of the arc. He is further indebted to Dr. H. H. Poole for help in the standardization of the photo-electric cells and for the benefit of his advice, and to those who assisted in the erythema tests. Acknowledgments have already been made to the staff of the M.O.H., Plymouth.

SUMMARY.

1. A vacuum sodium photo-electric cell, made of glass, was used with a microammeter to show that with a mercury vapour arc:—

(*a*) It is advisable to run the lamp continuously for successive treatments, exposures being made six minutes after switching on.

(*b*) After 35 or 40 minutes' use the current should be switched off for a

minute or two to enable the lamp to cool, thus regaining its initial potency 5 minutes after switching on again.

(*c*) The loss of potency due to over-heating is a real phenomenon, and is not due to fatigue in the photo-electric cell leading to erroneous readings.

(*d*) The increase in ultra-violet radiation on switching on lags somewhat behind the increase in total radiation, but a maximum is obtained 6 or 7 minutes from the start.

(*e*) Irregularities in the radiation emitted are not due to chance air-currents unduly cooling the lamp; these only give a decrease of 3–6 per cent., if any. The irregularities may be due to irregularities in the town supply voltage.

2. The aluminium reflector of the mercury arc used, when adjusted to its position of maximum efficiency, increases the total radiation to about 2·7 times and the ultra-violet radiation about 2·0 times. This more than counterbalances any loss of efficiency in the lamp due to overheating occasioned by the reflector. When the reflector is used the decrease in intensity with distance is considerably less than that calculated according to the inverse square law.

3. As compared with a new lamp, one which had had about 750 hours' use emitted in the blue, and ultra-violet, 40 per cent. of the radiation, in the ultra-violet 36 per cent., and in the anti-rachitic ultra-violet 24 per cent. Its effect was then so weak clinically that its use was discontinued, on the ground of economy in time of exposure.

4. J. H. J. Poole's neon lamp method is very convenient for the study of the behaviour of a mercury vapour arc.

5. At 61 centimetres a new mercury arc may produce slight erythema in one minute, and definite erythema in two minutes. Exposure to noon sunlight of intensity 93 thousand metre candles (carbon arc standardization) produces erythema in 30 minutes, though some effect is produced in 10 minutes and upwards.

6. Beck's ultra-violet fluorescence spectroscope was found useful for visual qualitative determinations of the transmission of light filters and for observations upon sunlight. The anti-rachitic rays are seen to be transmitted to some extent on clear days in November.

7. Approximate photo-electric determinations of the ratio of total to diffuse ultra-violet show that even at midsummer noon the sunlight is not very much more potent than the diffuse light from the whole sky, and the direct light must be relatively less at other times.

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No. 6.

SOME EXPERIMENTS ON THE ACCURACY OBTAINABLE WITH GAS-FILLED PHOTO-ELECTRIC CELLS.

By W. R. G. ATKINS, Sc.D., F.R.S.

[Read April 28. Published separately May 26, 1931.]

In the course of measurements of submarine illumination Dr. H. H. Poole and the writer had occasion to use a Kunz gas-filled potassium hydride cell (obtained from the Central Scientific Co., U.S.A.), standardized against a vacuum potassium cell. These were mounted in photometers, designated K and G, respectively. At low anode potentials, 3 volts for K and 60 volts for G, the ratio of their sensitivities remained sensibly constant, but at higher voltages K was liable to vary, so that its standardization, in the water, at 120 volts might be 30 per cent. less when ascending than when descending 30 to 60 minutes before. It was found that even greater variations were likely to occur if the cell had been exposed to bright light with a high anode potential, so that a current of more than a few micro-amperes was obtained. For this reason the cell was never so exposed that the current exceeded a few micro-amperes. Our results were criticized by Kunz and Shelford (1930), who used gas-filled cells, standardized once for all in the University of Illinois, and then used for measurements in Puget Sound (1922) or in fresh-water lakes; though more recently Shelford (1930) admits the value of checking against a vacuum cell. We are indebted to the staff of the Research Laboratory of the G.E.C. for advice concerning what they consider to be the best way of using a gas-filled cell, which, at its best, does not approach the accuracy obtainable with a vacuum cell. Instead of restricting the current they recommend the momentary passage of the glow discharge by raising the voltage sufficiently; the measurement is made immediately afterwards, while the cell is in its most sensitive condition. This method was adopted in our subsequent work at sea (1931). The experiments here described were undertaken to ascertain the accuracy thus obtainable with gas-filled cells, namely, a thick-film caesium cell bought in 1927 from the Cambridge Instrument Co. and believed to be prepared according to the recommendations of Professor Lindemann of Oxford, and a potassium gas-filled cell from the General Electric Co. in 1928. This embodies various advances made since the earlier potassium cell was obtained in 1924. Both cells were suitably mounted under opalized glass.

As a constant source of illumination a 6-volt, 18-watt vacuum lamp was used, mounted in a white enamelled iron reflector, the rim of which was in contact with the photometer window. This was run at 5·50 volts, adjustments

of the series rheostat being made when required. Small variations in voltage around 5·50 caused a change of illumination of 80 per cent. per volt, consequently the voltmeter had to be watched carefully. As the lamp is only used for such tests on photo-electric cells and at a voltage well below that at which it is rated, its candle-power should remain sensibly constant.

Fig. 1 shows the voltage-sensitivity curve for the caesium cell at constant illumination as explained in the legend. The irregularity around 100–120 volts was occasioned by a change in the source of high tension, another battery being added.

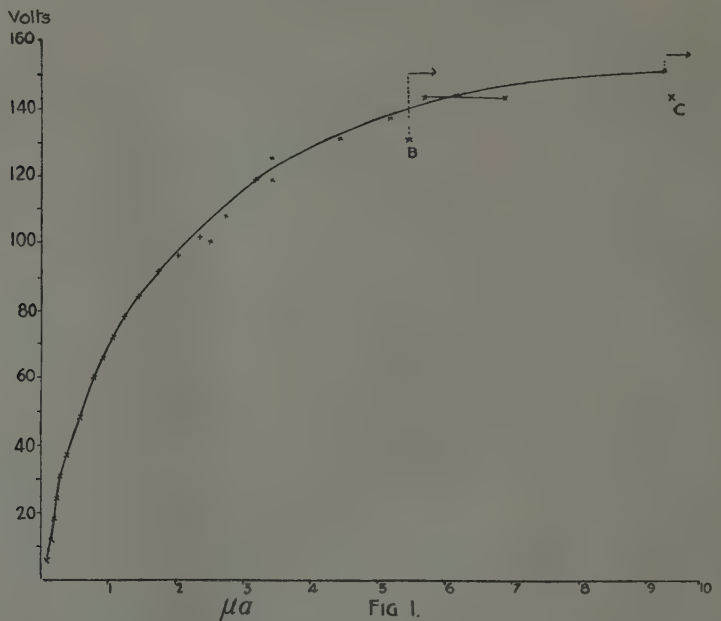

FIG 1.

Voltage sensitivity curve of a gas-filled caesium cell. The ordinates show anode potential, the abscissae current in micro-amperes at constant illumination. The horizontal line at 140 volts denotes successive readings with no alteration in adjustment. The line with arrow denotes rapid increase in current leading to glow off the scale. B denotes reading after the first glow and C after the second, both taken immediately after.

At lower and medium voltages the cell behaved reasonably well. Thus at 12·0 volts the current was 0·18 micro-ampere, which was exactly recovered after the voltage had been raised to 48 and brought back to 12. Again at 60·2 volts the current was 0·83, and 0·81 μa was obtained on coming down from 108 volts. The readings at B and C (Fig. 1) immediately after the first and second glow discharges, viz., 5·7 μa at 132 v. and 9·2 μa at 144 v., lie about the same distance below the curve obtained before the discharges. This cell would appear to behave more regularly when the current is limited to under 2 μa.

Fig. 2 illustrates the behaviour of this cell on prolonged constant illumination at constant anode potential after a glow discharge and after successive discharges.

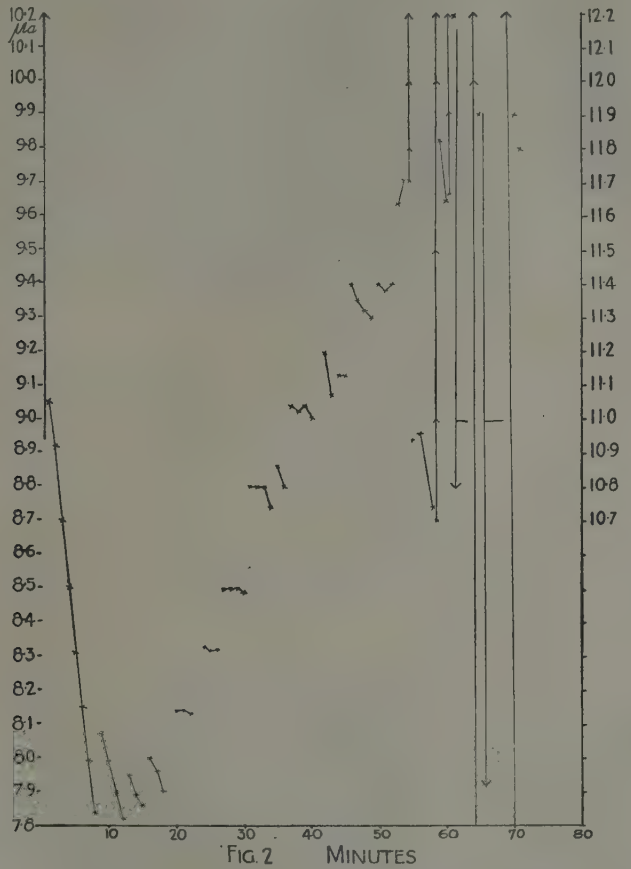

FIG. 2

Behaviour of gas-filled caesium cell. The ordinates denote current in micro-amperes; the abscissae time in minutes. The left-hand ordinates apply up to the glow discharge at 54 minutes, after which those on the right should be read. A line with arrow-head pointing upwards denotes a glow discharge; arrow-head pointing downwards denotes switching off of the light for a period shown by the horizontal line drawn at right angles to the arrow opposite 11 μa. Readings taken without adjustment of the lamp are joined by a line, adjustment being effected when the lamp-voltage was judged to be as much as 0·01 volt below 5·50 volts. The anode potential was 143 volts, save when glowing.

It may be seen that the glow discharge leaves the cell in a highly sensitive state, which rapidly falls off, decreasing about 2 per cent. per minute for 5 minutes, after which it stays fairly constant for about 10 minutes, and then rises, ultimately exceeding its original post-glow sensitivity—giving the reading

9·7 as against 9·05 μa. This is probably a temperature effect, as the vapour pressure of caesium is not negligible. It may, however, be thought peculiar that such sensitivity increase should always occur after adjustment of the lamp voltage, so as to appear to proceed by steps. This is probably due to the fact that in adjusting back up to 5·50 volts a momentary increase well above that voltage usually occurs, with a correspondingly large increase in current through the cell. The glow usually occurred at 151 volts, but once not till 156 and once not till 162 volts. Combining this and previous series the post-glow readings for constant illumination were 8·85, 8.95, 8·88, 8·00*, 8·30, 9·70, 8·12, 8·75, 9·05, 10·94, 11·83, 12·30 μa. The value with asterisk was obtained after the glow had been allowed to pass, accidentally, for perhaps half a minute. Such results can hardly be considered as suitable for quantitative measurements. Had the voltage been 60–90 and the current 2–3 μa, more regular readings might have been obtained, but the temperature effect would none the less have

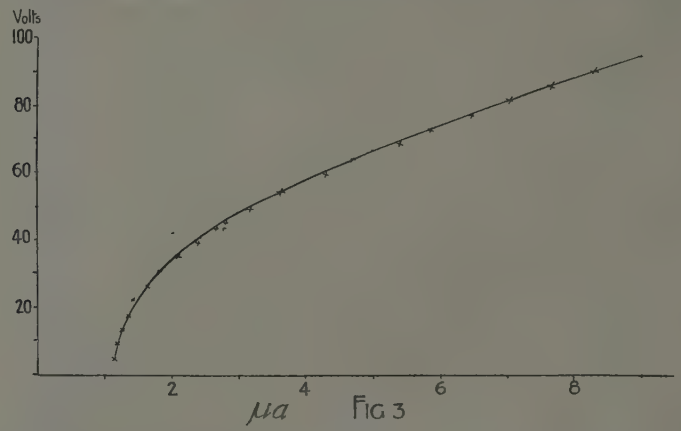

FIG 3

Voltage sensitivity curve of gas-filled potassium cell, ordinates being anode potential, and abscissae current at constant illumination.

come in. It seems, however, that one might use this cell with advantage to ascertain the approximate ratio of green to orange or green to red in determining the colour of daylight, as explained elsewhere (1931), by taking quick successive readings with colour filters, since the sensitivity of the thin-film caesium cell, type C.M.V. 6, is low in the green. The desire so to use it was the reason for selecting the caesium cell for test; it was also selected because on account of the temperature effect it probably represents the gas-filled cell at its worst.

The transmission factors of the blue, green, yellow, and red filters of Corning glass (see Atkins and Poole, 1931), as found by the caesium cell illuminated by the test lamp, were respectively 1·3, 13·3, 18·1, and 7·0 per cent. That for the green filter in daylight, which falls more obliquely on the average, was 9·8 per cent.

Fig. 3 shows the voltage sensitivity curve for the gas-filled potassium cell,

its behaviour being quite normal. The curve was continued further than has been shown; between 100 and 150 volts the current rose to 25 μa, and up to 64 μa at 190 volts. After that a very rapid rise took place, to 172 μa at 200 volts. In this region, of course, precise measurements would be impossible; about 180 volts seems to be the most this cell could be used to, or 50 μa as a maximum of current. This is less than may be reached with a large vacuum cell in strong light; but even the weak light of the test lamp may give it at the proper voltage, hence the value of the gas-filled cell. It has been shown by Campbell and Ritchie, however (1929, Fig. 15), that for all lights strict proportionality between current and illumination is limited to currents of less than 2–3 μa for the type and size of gas-filled cell they used. Their chapter on photo-electric emission should be consulted.

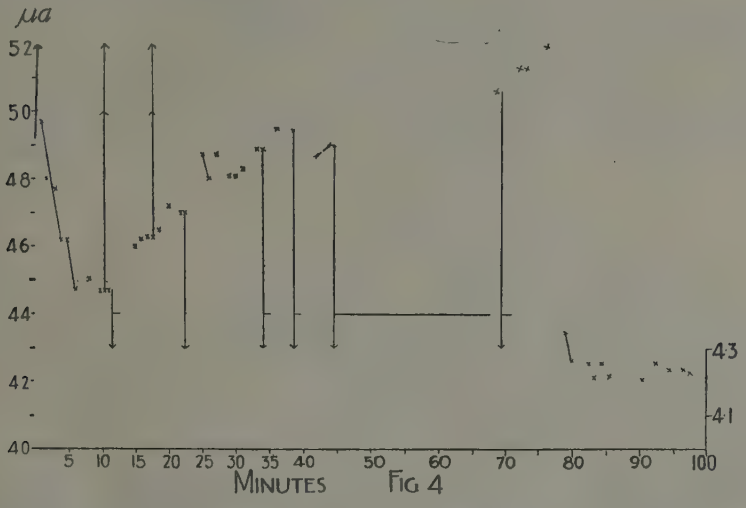

FIG 4

Behaviour of gas-filled potassium cell. The ordinates show current in micro-amperes, the abscissae time in minutes. The left-hand ordinates apply up to 76 minutes; the right-hand ordinates, one-tenth scale, apply from 79 minutes onwards. The notation is as in Fig. 2, also test lamp conditions; anode potential, 166 volts.

Fig. 4 shows the result of exposing the gas-filled potassium cell, J, to constant illumination between glow discharges, also the effect of short periods of rest. The voltage chosen, 166, with current 44–52 μa was, unfortunately, rather too high in the light of subsequent experience. As with the caesium cell there is a rapid fall in sensitivity after the glow discharge, the rate being closely the same, 2 per cent. per minute for 5 minutes. After that the readings were approximately constant for 5 minutes and then rose slowly, so that readings greater than the initial post-glow reading were obtained even after rest with current off. The successive post-glow readings were 49·2, 49·7, 44·7*, 46·5* μa at 166 volts, and 5·02, 4·94, and 5·09 μa at 59 volts. There is a doubt as to whether the glow was actually reached in the case of the readings with asterisk,

because, though the needle of the micro-ammeter gave the sudden throw characteristic of the glow discharge, the immediate pre-glow and post-glow readings were almost identical. Omitting these two, the variation is less than 2 per cent., equivalent to a difference of a minute between the intervals between the glow and the reading in successive instances. Judging from the values from 80 minutes onwards, the test lamp can usually be set to give an accuracy of 1 per cent. in its illumination.

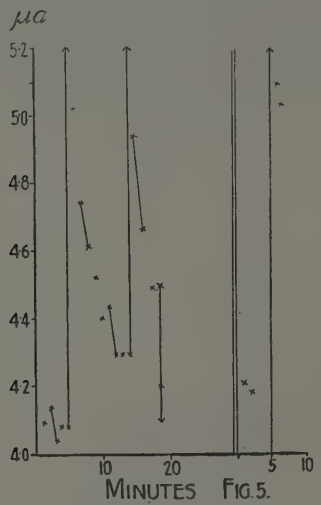

FIG. 5.

As Fig. 4, but with 59 volts anode potential. The double line denotes an interval of 47 hours.

Fig. 5 is similar to Fig. 4, but at 59, instead of 143 volts. The post-glow rate of decrease is 3·3 as against 2 per cent. The effect, upon the sensitivity, of a 47-hour period of darkness is shown, the two successive readings being 4·49 and 4·21 μa; but if we take a reading obtained at the end of the rapid post-glow decay period, we get 4·29 and 4·21 μa respectively. The difference between the initial reading, 4·04, and the maximum post-glow value, 5·09, is close to a 20 per cent. variation with 59 volts, the corresponding minimum and maximum readings at 166 volts being 44·7 and 52·0 μa, a range of about 14 per cent. It seems, therefore, that with very small currents still greater percentage variations would be found to occur between the resting and post-glow sensitivities. This potassium cell seems to give results which can be relied upon to within 2 per cent. for post-glow readings for moderate currents, up to at least 5 μa. The results refer, of course, to measurements made within a short period of time, and offer no evidence as to the constancy or inconstancy of the cell over long periods.

SUMMARY.

1. A gas-filled caesium hydride cell was tested for constancy of emission after the glow-discharge had been passed momentarily; a variation of about 33 per cent. was found at 143 volts anode potential.

2. Immediately after the glow-discharge the sensitivity decreases at a rate of about 2 per cent. per minute. It was, however, found to rise subsequently.

3. A gas-filled potassium hydride cell was similarly tested for constancy of emission, and the variation was found to be within 2 per cent. with current of about 5 μa, anode potential 59 volts; at 166 volts the constancy appeared to be somewhat less. No tests were made as to the constancy or otherwise of the cell over prolonged periods.

4. The rate of decrease of sensitivity after the glow amounts to about 2 per cent. at 166 volts, and over 3 per cent. at 59 volts. It is, therefore, advisable to make measurements immediately after the discharge, which should be of momentary duration only. From this it follows that if Poole's neon lamp method be used to integrate the current, such integration should be over equal periods of time in each case rather than for an equal number of flashes of the lamp.

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No. 7.

A METHOD OF DISTINGUISHING CERTAIN STRAINS OF NEW ZEALAND PERENNIAL RYEGRASS (*LOLIUM PERENNE*, L.) BY EXAMINATION OF SEEDLINGS UNDER SCREENED ULTRA-VIOLET LIGHT.

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[Read April 28. Published separately May 18, 1931.]

(Plate 1.)

Introduction.

In a recent paper (Mercer and Linehan [7]) the authors reported some preliminary results of investigations upon the value of screened ultra-violet light as a means of differentiating seeds of *Lolium perenne*, L. from those of *Lolium multiflorum*, Lam., in the absence of awns. This test, which was suggested by Gentner [2] in 1929, depends upon inspection under screened ultra-violet light of wave-length 3000 to 4000 A.U. of germinated seedlings grown upon white filter paper. Under these conditions, those portions of the paper adjacent to the rootlets of *L. multiflorum* exhibit a bright bluish fluorescence, while no fluorescence appears in the case of *L. perenne* (see Plate 1). Verification of the test involves growing-on trials, and these, as well as genetical experiments on the inheritance of the fluorescence character, are being conducted by the authors and will be reported in due course.

In the present paper the results of fluorescence tests on certain samples of New Zealand perennial ryegrass are presented, and an attempt is made to correlate the proportion of fluorescence-reacting seedlings present in a sample with its district of origin. The results are of interest, and, if of general application, would seem to warrant the conclusion that the use of the ultra-violet light test provides a ready laboratory method for distinguishing seed samples of the valuable Hawke's Bay strains from those inferior ones emanating from other districts of New Zealand.

The Agronomic and Commercial position of New Zealand Ryegrass.

New Zealand perennial ryegrass is produced mainly in the districts listed below, the relative commercial importance of which may perhaps be gauged by

the number of samples from each examined in the New Zealand official seed testing station during the years 1928 and 1929. Details of these according to Foy [1] are as follows:—

Place of Origin.	Number of Samples. 1928.	1929.
Southern	1,497	797
Canterbury	336	258
Sandon	117	127
Hawke's Bay	101	223
Poverty Bay	45	51

It seems clear from these figures that the South Island areas are much the most prolific.

The agronomic value of perennial ryegrass strains from the sources mentioned has been investigated by Levy and Davies [5, 6]. Their researches suggest a definite correlation between the agronomic characters of strains and their respective districts of origin. The results of these workers' strain analysis of commercial lines of perennial ryegrass of stated origin are reprinted in Table I.

TABLE I.

Strain Analysis of 841 Lines of Commercial "Perennial" Ryegrass of stated Districts of Origin. From Levy and Davies [6], p. 370.

District of Origin.	True Perennial. Types 1 and 2.* Number of Lines.	Best type of False Perennial. Type 3. Number of Lines.	False Perennial. Types 4 and 5. Number of Lines.	Dominant Italian. Type 6. Number of Lines.	Total number of Lines under Trial.	Percentage of True Perennial.
Hawke's Bay	175	1	8	5	189	93
Poverty Bay	32	...	2	1	35	92
Sandon	46†	3	8	7	64	72
Mid. & North Canterbury...	7	16	56	17	96	7
South Canterbury ...	3	9	38	34	84	4
Southland	3	27	269	9	308	1
Maniototo	2	4	16	2	24	8
Wairarapa	5	1	3	3	12	42
Marlborough	2	7	1	1	11	18
Imported	1	9	7	1	18	6

* But may contain a trace of some Italian ryegrass.

† Many lines contain a fair percentage of Italian.

As may be seen from this table, the Hawke's Bay and Poverty Bay lots are, in the main, quite distinct in type from those of Southland, Canterbury, and other districts. The same workers (*loc. cit.*) have shown, furthermore, that under New Zealand conditions the lots containing a high proportion of what they designate "true perennial" types, such as Hawke's Bay and Poverty Bay strains, are very much superior, from an agronomic point of view, to those strains from other districts, which contain a low proportion of "true perennial" types. This superiority embodies greater ability to make rapid growth after cutting or grazing, greater persistence under grazing conditions, and greater resistance to disease. In contrast with "true perennial" the same authors distinguish a "pseudo" or "false" perennial type, characterized by lack of tillering capacity and by inability to persist. As will be seen from Table I, this type constitutes the major portion of the South Island lots.

Jenkin [4], in Wales, has had New Zealand perennial ryegrass strains under trial, and he, also, concludes that the material examined by him may be divided into two classes, one ("Class A") being a very useful long-lived type (certain of the Hawke's Bay and Poverty Bay kinds), and the other ("Class B") a very inferior short-lived one (including the Southland, Canterbury, etc., lots).

The considerations adduced in the foregoing paragraph emphasize the importance of provenance in the case of New Zealand commercial perennial ryegrass. Unfortunately, it would appear that importations of New Zealand ryegrass seed into Great Britain come prinicipally from those districts which produce inferior types. Levy and Davies [6] state that "the whole supply of the South Island towns, being drawn from local sources, is preponderantly of the 'false perennial' types; the data emphasize really that these towns are export centres sending considerable quantities of their ryegrass to the North Island and overseas." It should be mentioned, however, that the New Zealand authorities (*vide* Hadfield [3]) are fully alive to the necessity of developing, for home use and for export, their valuable Hawke's Bay strain, for the Department of Agriculture [3] in 1929 initiated an extensive certification scheme for true perennial ryegrass of the type grown in the Hawke's Bay district.

In view of the fact that New Zealand commercial perennial ryegrass, as at present on the British and Irish markets, consists of a mixture of valuable and relatively worthless strains, it is obvious that the possibility of distinguishing them by seed examination in the laboratory is a matter of moment. Concerning this, Jenkin [4] writes: "This variation in the type of New Zealand seed cannot be over-emphasized, and while the British farmer can with every confidence be urged to use 'Class A' New Zealand seed and with equal confidence to reject 'Class B,' there is, as yet, no sure means by which he can differentiate between them in the sample."

Some of the inferior South Island lots apparently contain a fair proportion of Italian ryegrass seeds, which ordinarily have awns attached, and hence are easily distinguished. Italian ryegrass seeds are not, however, always awned. Occasional seeds, particularly those from the lowermost florets of the spikelet, lack this character. In addition, it frequently happens that a proportion of

the awns is mechanically removed during threshing and cleaning. According to Levy and Davies [6], apart from this Italian ryegrass element, the main bulk of the inferior New Zealand perennial ryegrasses is of the "pseudo-perennial" type. In this form short awns or awn points are frequently present, but in many lines most of the seeds are awnless. The remark above concerning mechanical removal of the awns during threshing of ordinary Italian, applies equally to this "pseudo-perennial" type, and the authors quoted refer to instances where such seed was subjected to hard dressing in order to remove awns.

It would appear, therefore, that the presence or absence of awns is of little value for laboratory identification of the two main types of New Zealand perennial ryegrass. One may go further and say that no seed characters of diagnostic value for these types have yet been recorded.

Experimental.

In order to obtain data concerning the proportion of fluorescence-reacting individuals present in samples of commercial perennial ryegrass from various districts in New Zealand, a number of lots have been examined under screened ultra-violet light. These samples were originally obtained by one of us from Dr. E. Bruce Levy, whose ready help we gratefully acknowledge. Dr. Levy informs us that these samples were drawn from commercial parcels, and were fairly representative of the various types to be found in New Zealand seed markets. In all, 43 samples were tested. Of these, about half came from the Hawke's Bay area, and the remainder from Canterbury, Southland, and other localities.

The method of testing has already been described by the authors elsewhere [7]. Briefly, it is as follows: a number of seeds (in earlier tests 100 seeds, in later ones 200 seeds were used by us) are allowed to germinate on white Whatman filter papers, moistened with tap water, on a Copenhagen (Jacobsen) germination tank, such as is ordinarily used in routine seed testing. When the roots begin to develop, that is, after 4–6 days, the filter paper is examined under screened ultra-violet light[1] of a wave-length of between 3000 and 4000 A.U., and those seedlings whose roots have caused fluorescence in the filter paper are removed and recorded (see Figs. 1 and 2). The remaining seedlings are transferred to fresh filter papers and replaced on the germination tank. These are re-examined at intervals of 2 or 3 days, and the test is continued for a period of about 21 days from the time of first putting up the seeds for germination. We would draw attention to the necessity for continuing the test for such a long period; although the majority of reacting seedlings "fluoresce" within 10 days, we have had experience, in a few cases, of fluorescence occurring after the seeds had been on the germinator for 17 days.

The results given by some forty-three samples of New Zealand origin are presented in Table II.

[1] In these tests an analytical quartz mercury-vapour lamp, supplied by Messrs. Hanovia, Limited, Slough, Bucks., was used.

TABLE II.

Showing the proportion of Fluorescence-reacting Seedlings arising from the Unawned Seeds present in samples of Commercial Perennial Ryegrass (*Lolium perenne*, L.) from certain districts of New Zealand

GROUP I.				GROUP II.			
Station Number.	District of Origin.	Number of Seeds Tested.	Percentage of Germinated Seedlings showing fluorescence.	Station Number.	District of Origin.	Number of Seeds Tested.	Percentage of Germinated Seedlings showing fluorescence.
N.Z. 1	Hawke's Bay	100	1	E. 452	Southland	200	13
N.Z. 2	,,	100	3	N.Z. 28	,,	100	59
E. 439	,,	200	2	N.Z. 29	,,	100	6
E. 440	,,	200	1	N.Z. 30	,,	100	98
E. 441	,,	200	1	N.Z. 31	,,	100	81
E. 442	,,	200	2	E. 454	,,	200	19
E. 443	,,	200	2	E. 455	,,	200	97
N.Z. 8	,,	100	3	E. 456	,,	200	9
N.Z. 9	,,	300	4	N.Z. 33	Canterbury	100	15
E. 444	,,	200	2	N.Z. 34	,,	100	14
E. 445	,,	200	3	N.Z. 35	,,	100	100
E. 446	,,	200	1	N.Z. 36	South Canterbury	100	11
N.Z. 10	,,	100	1	N.Z. 37	,, ,,	100	94
E. 447	,,	200	1	N.Z. 38	,, ,,	100	94
E. 448	,,	200	1	E. 453	Marlborough	200	33
E. 449	,,	200	4	N.Z. 42	,,	100	15
E. 450	,,	200	1	N.Z. 39	Wairarapa	100	10
E. 451	,,	200	0	N.Z. 43	Central Otago.	100	96
E. 457	,,	200	1	N.Z. 40	Maniototo	100	71
E. 458	,,	200	2				
E. 459	,,	200	1				
E. 460	,,	200	2				
E. 461	,,	200	2				
E. 462	,,	200	1				
	Average for Group I ...		2		Average for Group II ...		49

It will be seen from this table that the lots tested fall readily into two groups. In the first group are the Hawke's Bay strains which show percentages of fluorescence-reacting seedlings of from 0 to 4, with an average of 2. In the second group are strains from Southland, Canterbury, Marlborough, Wairarapa, Central Otago, and Maniototo. Among members of this group the fluorescence percentages range from 6 to 100, and average 49. It will be noted further, that in group 1, only in two lots out of a total of twenty-four is the fluorescence percentage *greater* than 3, and that in group II, only in two cases out of a total of nineteen is the fluorescence percentage *less* than 10. It would, therefore, appear, in so far as the results can be considered significant, that seedling analysis under the quartz lamp provides a useful means of distinguishing between the valuable Hawke's Bay strains and those inferior ones from other New Zealand districts. It is probably safe to assume that a New Zealand sample showing 5 per cent. or more positive results is not a pure Hawke's Bay strain.

Discussion.

It will be of interest to discuss, briefly, the possible causes which result in the Hawke's Bay perennial ryegrass strains giving a lower proportion of fluorescence-reacting seedlings than those from more southerly districts. As mentioned in the introduction to this paper, *Lolium multiflorum,* Lam., exhibits the fluorescence reaction when its seedlings are examined under the quartz lamp. Gentner [2], who first noted the phenomenon, does not cite any exceptions, and Mercer and Linehan [7] found the test positive in *every* case when 3,333 seedlings of awned ryegrass were examined. Nilsson [8] obtained similar results from commercial samples of Italian ryegrass, but found that certain Italian ryegrass plants, on being artificially self-fertilized, gave a proportion of non-fluorescent seedlings in their progeny. He nevertheless concluded that Italian ryegrass seedlings are normally fluorescent. In the case of *Lolium perenne,* L., Gentner [2] states that the reaction is negative, but adds (in correspondence) that exceptions occur in about 10 to 20 per cent. of cases. Nilsson [8] reports a general absence of fluorescence in *Lolium perenne,* but found a number of exceptions among named strains, and, as in the case of *Lolium multiflorum,* observed both fluorescent and non-fluorescent seedlings in the progeny of certain selfed plants. The present authors [7] found that on the average about 10 per cent. of the awnless seeds present in commercial samples described as Irish, or Scotch, perennial ryegrass, show the fluorescence character. Before this 10 per cent. can be classed as *Lolium perenne* individuals showing departure from the general rule of non-fluorescence, it is necessary to carry out growth tests in order to examine the botanical characters of the resulting plants. Such tests are at present being carried out, but are not yet mature. Observations made, however, during the early stages of growth, make it fairly certain that at least a considerable proportion of these aberrants arise, in reality, from Italian ryegrass seeds whose awns have been lost.

It will, perhaps, be germane to this discussion to refer briefly to the genetical aspect of the presence and absence of the fluorescence character in *Lolium*, though our experiments in this branch of the enquiry are as yet incomplete. There is already evidence to show that the fluorescence character is of a heritable nature, and that it can be introduced into *L. perenne*, from which variety it is apparently normally absent, just as *L. multiflorum* can be obtained without it. The present authors self-fertilized a number of individual plants of perennial and of Italian ryegrass during the summer of 1930, by enclosing about 5 inflorescences of each plant in a glazed paper bag, and allowing them to flower in a cool greenhouse. A number of perennial ryegrass plants so treated gave progeny among which a proportion of reactors to the quartz lamp test appeared. The progeny of similarly selfed Italian ryegrass plants *all* proved fluorescent, but the number of individuals tested was small (by reason of a high degree of self-sterility among the plants examined), and, as has been mentioned, Nilsson reports, in a paper recently to hand [8], that he found a number both of Italian and of perennial ryegrass plants which on selfing produced *fluorescent as well as non-fluorescent progeny.*

It would, accordingly, appear, in the light of present knowledge, that perennial ryegrass is normally non-fluorescent, and that Italian ryegrass is normally fluorescent; but since fluorescence seems to be a genetical character, and since the varieties in question readily intercross producing fertile hybrids, the character may, by hybridization, be introduced into perennial ryegrass individuals or eliminated from those of Italian ryegrass.

It seems likely that the inferior New Zealand strains of ryegrass have arisen, at any rate in part, as a result of hybridization of perennial with Italian ryegrass. In referring to the "false" perennial types which largely constitute the Southern strains, Levy and Davies [6] express the opinion that these "are derivatives, first by strain selection towards short-lived perennials, followed by an intercrossing of this type with Italian ryegrass." Jenkin [4] corroborates this view, and having also referred to the possibility of these Southern strains having arisen through selection of inferior types of perennial ryegrass, says: "it is further possible that they have been developed through the inter-crossing of the 'commercial'" (perennial ryegrass) "and Italian."

This theory concerning the origin of the perennial ryegrass of Southern New Zealand districts furnishes a possible explanation of their giving a large proportion of fluorescence-reacting seedlings, for it is highly probable that the reacting individuals among them are, in reality, segregants, bearing fluorescence factors, of crosses between perennial and Italian ryegrass plants.

In conclusion, it will not be irrelevant to point out one or two lines of possible development, the exploration of which may be profitable. On the probability of the approximate rule that pure *L. perenne*, L., gives "non-fluorescent" seedlings and pure *L. multiflorum*, Lam., "fluorescent," it is possible that the non-fluorescent character may be associated with longevity, which, from an agronomic point of view, constitutes a principal difference between perennial and Italian ryegrass. Should the trials now in hand

bear out this possibility, the potential value of the quartz lamp test, to plant breeders engaged upon the ryegrasses, immediately becomes apparent, since the only reliable test for longevity at present is a protracted growing trial. Selection among existing types, from mature plants, would also be facilitated, since we find the reactive seedling retains the capacity for fluorescence in its roots, when mature. The question of the dominant or recessive nature of the factor or factors for fluorescence, and that of possible linkages, will at once appeal to the geneticist. Evidence is too sparse, at present, to justify any dogmatic pronouncement upon either of these questions, but it may be observed that the tendency of such evidence as we have, so far, accumulated, is towards dominance of the "fluorescence" factor (or combination of factors). Investigations on the lines indicated are being continued.

Summary.

1. New Zealand perennial ryegrass consists of a number of different strains, which vary in their agronomic value.

2. Of these, the Hawke's Bay strains are much superior to those of South Island origin.

3. The importance of being able to distinguish the good from the bad strains by laboratory tests on seed samples, is noted.

4. When the awnless seeds from some 43 samples were germinated on white filter paper and the seedlings examined under screened ultra-violet light, it was found that the Hawke's Bay strains showed percentages of fluorescence-reacting individuals ranging from 0 to 4 with an average of 2. Similar tests on South Island lots gave results ranging from 6 to 100 per cent. reacting seedlings with an average of 49.

5. It is tentatively suggested that samples showing more than 5 per cent. reactors are not of pure Hawke's Bay strain.

6. The possible causes of the relatively high proportion of fluorescence-reacting seedlings in produce from the southerly districts of New Zealand are discussed.

We desire to record our debt for laboratory assistance, in pursuit of these experiments, to Mrs. W. Carson (formerly Miss Ruth Lockhart), Miss Dorothy Mark, and in connection with photography to Miss Roy Stuart, all of the Official Seed Testing Station for Northern Ireland.

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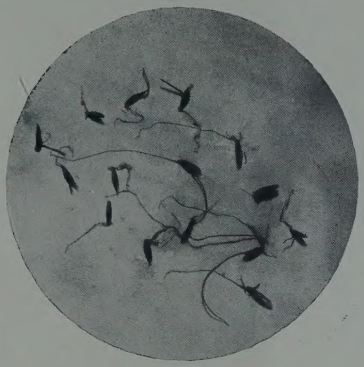

FIG. 1.—APPEARANCE PRESENTED BY "NON-FLUORESCENT" SEEDLINGS OF *Lolium* IN SCREENED ULTRA-VIOLET LIGHT.

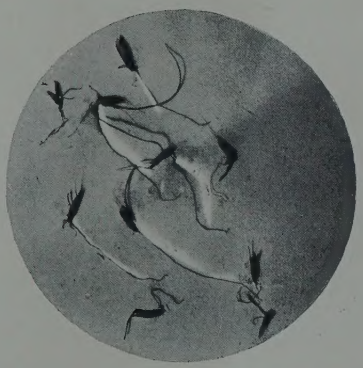

FIG. 2.—APPEARANCE PRESENTED BY "FLUORESCENT" SEEDLINGS OF *Lolium* IN SCREENED ULTRA-VIOLET LIGHT.

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